ROBERT HOPE-JONES: THE EVOLUTION OF HIS ORGAN ACTIONS IN BRITAIN FROM 1889 TO 1903

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... sit thee down and write
In a book, that all may read
William Blake

Damn the age; I will write for Antiquity!
Charles Lamb

Robert Hope-Jones, 1894

" until biographies be written ... , my friends cannot know why I fail to hold the place I gained as leader of the world in organ building"

To my friend Lucien Nunes, without whose interest, expertise and assistance this work would have been by far the poorer

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- v1.2 - Appendix 1 (coupling at St John's, Birkenhead)
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- v2.6 - Completely revised and updated
- v2.7 - Various minor amendments (including to Reference list)
- v2.8 - Dedication inserted

Foreword to version 2.6

This document was first written in 2009 and, after some revisions, it reached version 2.5 in 2010. This then remained stable over the next ten years, during which it became widely read and quoted the world over as the most extensive and dependable reference source on Hope-Jones's electric organ actions ever made available in the public domain. However by 2020 it had become clear that an update was overdue, since additional information had accumulated such as that relating to further subtleties of Hope-Jones's action magnet and the power-saving systems applied to several of his mechanisms. In addition much detailed editorial work was necessary, for example to bring the list of references up to date largely because of the rampant and accelerating 'link rot' which reflects the ephemeral and unreliable nature of so much material on the internet today. A new chapter has also been added to address the 'master reset' problem resulting from the use of non-volatile bistable mechanisms in organ actions. As a result it is hoped that this meticulously revised version will continue to meet the obvious need demonstrated by the enthusiastic reception of the previous one, by which I remain simultaneously surprised and gratified.

C E Pykett
May 2020

Abstract

This article shows that Hope-Jones's organ of 1889 at St John's, Birkenhead was the first in the world whose action was designed from the outset as an integrated *system* by a gifted professional engineer, using electricity to control not only the key action but the speaking stops, couplers, pistons and swell shutters as well. One of the key elements facilitating the integration was Hope-Jones's action magnet, whose design was subtle and which is discussed at length in the article.

The article also traces the evolution of Hope-Jones's subsequent thinking and practice until he left for America in 1903. His key actions remained fairly static, consisting of pneumatic amplifiers controlled by his action magnet. However his speaking stop actions evolved progressively from organs in which all stops were on slider chests to those in which some ranks were conceived on the unit principle. The progression was nevertheless fairly slow considering that Hope-Jones had completed his paper design for the fully unified organ by 1890 at the latest, and the article suggests that this was due to a mixture of technical and commercial considerations. There is little doubt that the power supply limitations of the day prevented him building the power-hungry unified organ with its hundreds or thousands of individual pipe actions, and he was probably not in a position to have manufactured them economically in any case.

Hope-Jones introduced several techniques for coupling, of which his electropneumatic ladder relay was undoubtedly the prototype for that used in the Wurlitzer theatre organ many years later. The article discusses the design features of this in detail. He also used relays of a different design in his mobile and therefore remote consoles because wind would not have been available. Likewise he must also have used both electropneumatic and (probably) electromagnetic stop combination actions depending on whether the console was mobile or not, and these are both discussed. Of the many swell shutter control techniques which he invented, there is some evidence that he was using individual electropneumatic actions for each shutter as early as 1894.

Although the organ at St John's used a dynamo to supply the action current, Hope-Jones devoted much subsequent effort to minimising the power consumption of his organs and some of his techniques are described in the article. This was forced on him because of the need to establish a customer base in the majority of the country which did not enjoy access to mains electricity, town gas or high pressure water for blowing the instruments and thus for driving a dynamo also. In these cases he had to use accumulators and some of his later organs would also have run for limited periods on a battery of dry cells, though definitely not on a single cell as he loudly and frequently claimed. In all of this he was at a disadvantage because of the low resistance of his action magnet and thus its high power consumption relative to those of his competitors. It is unfortunate that he degraded himself by the shrillness and mendacity with which he insisted the opposite was the case.

With the exception of unit chests and their means of control which he introduced only a few years later, the 1889 organ at Birkenhead contained all of the action, switching and circuit techniques which were immediately taken up and applied in electric actions worldwide. They were not displaced until electronics began to appear in organ building in the 1960's, and even today organs are still built or rebuilt with electromechanical actions and components which are functionally identical to those invented by Hope-Jones. That remains the measure of his legacy and achievements.

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Introduction

In the space of the mere fourteen years or so during which he was active in Britain Robert Hope-Jones changed the face of organ building across the globe for ever. Initially an enthusiastic amateur church musician with interests inclining strongly towards organ building, his day job was at first a senior telephone engineer, a position he had attained rapidly while still in his twenties. In his thirtieth year, 1889, he threw it up in favour of full time organ building, and until he suddenly emigrated to America in 1903 he and others built a large number of organs in Britain using a novel electrical system for controlling their key, stop and combination actions. Many of the techniques and components he invented have underpinned electric actions ever since. Therefore these dates which define the period when he was vigorously refining his ideas in Britain are those chosen for the purposes of this piece.

This is not a biographical article because Hope-Jones has already been done to death in this sense by countless authors, a significant number of whom have fallen into that fatal trap of worshipping their subject thus rendering them hagiographers rather than biographers. Among those who have maintained a more objective focus, their work has tended to illuminate the tonal aspects of his organs rather than the details of their mechanism. Therefore none of these authors has covered the technical side of his work in the detail of this article. Three relatively recent and useful sources are Relf Clark's PhD dissertation [38] and the biographies by David Fox [39] and Roger Fisher [5], though all lack the technical detail just mentioned. Clark, a solicitor who is also well qualified musically, produced a weighty two-tome thesis which languishes unpublished as far as I know in the depths of the library at Reading university, making it rather inaccessible and therefore of limited usefulness to all but the most determined seekers after truth. Fox's book is objective and therefore not hagiographic, but it is written from an American perspective which renders it regrettably superficial and incomplete regarding Hope-Jones's work in Britain. It also contains many errors. Naming just two, it becomes wearisome after a while to find Thomas Threlfall's (q.v.) name mis-spelt throughout, together with no mention of organs such as that at Pilton in its gazetteer of stop lists. Like Fox, Fisher also covers Hope-Jones's entire career in his readable little book, and its enjoyable style should not be allowed to conceal the fact that its author is a professional archivist in addition to his other interests. This means he is able to present several hitherto unknown details which had eluded other authors [1].

At the other end of the spectrum there exists a large and thoroughly unfortunate body of literature, a good proportion of which is scarcely worth reading other than for its entertainment value: the authors, some with impressive paper qualifications, seemingly vie with each other in the shrillness of their rantings directed at Hope-Jones. Appendix 3 contains examples of the less enthusiastic remarks made about him and his work over the last half-century or so, and although included as a light-hearted foil to the perhaps indigestible contents of the rest of this article, one feels some sadness that such things should have been penned by scholars.

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[1] Clark reviewed Fisher's book (in *Journal of the British Institute of Organ Studies (26)2002*) and wrote of him *"Mr Fisher modestly declines to supply a biographical note"*. As a result he concluded that *"one does not therefore know whether he is attracted by the impact of the contemporary arts on traditional forms of aesthetic experience"*.

Consequently there does seem to be a need for a more detailed study of Hope-Jones's early work at an engineering level before the limited information available becomes irrecoverably lost as time marches on. Therefore this article describes how the electrical aspects of his actions worked in some depth and it assumes some knowledge of circuits and organ mechanism on the part of the reader. Some of it merely draws together in one place information which is available elsewhere, though much novel material is also included. The latter has helped to uncover the truth beyond the fictional fog surrounding Hope-Jones, not a little of which was contributed by himself - despite his achievements, naughty old Robert sometimes wove a web of deliberate deceit which is still taken at face value by some. This means that one has to exercise caution when assessing everything he said and wrote during his lifetime, ranging from patent specifications to lectures and pamphlets. Therefore I have had to resort to a process of almost forensic inference several times during the writing of this article. An example concerns Hope-Jones's organs which had moveable consoles on the end of a long cable. These probably used a purely electric rather than an electropneumatic combination action (because no wind was available in the console), which in turn means they would have had to be powered by dynamos or accumulators (because dry batteries could not have provided the necessary peak current demand when the pistons were used). Also these organs probably used a particular type of combined keying and coupling circuit which was not used in others, or they had an array of keying relays at the organ end of the cable. Otherwise the circuit techniques of the day mean the cable would have been so fat that it simply could not have had the necessary flexibility. These constraints would not have applied to Hope-Jones's fixed consoles. To date I have not found any of this mentioned in the literature, though that does not mean it does not exist of course, but for this reason it is expanded in detail later.

Nevertheless there still remain gaps in this narrative, either because my knowledge is incomplete or erroneous (for which I apologise in advance) or because the information does not exist at all. The condemnation of Hope-Jones and his work for over a century has gone way beyond anything which could possibly be justified by objective scholarship, fuelled as it has been by bitter commercial rivalries, vicious unkindness and closet homophobia to name but three. The upshot, as we well know, is that almost nothing is left of his work when we now look for clues to close outstanding issues. However the stimulus to write the article first arose as the result of two initiatives in progress in 2009 which complemented nicely my own work and interests over many years previously. Neither seemed to be well known to the wider Hope-Jones scholastic community, assuming it merits the title. These initiatives were, firstly, the research done by the Lancastrian Theatre Organ Trust (LTOT) and particularly its unique museum in Manchester devoted to Hope-Jones [1], [2]. Secondly, the restoration of the Norman and Beard/Hope-Jones organ at the Battersea Arts Centre (formerly the Town Hall) in south London revealed some fascinating and hitherto unknown information before a disastrous fire destroyed much of the building and damaged the instrument in 2015. It is therefore fortunate that earlier versions of this article were written prior to this catastrophe. I remain indebted to the late Don Hyde and Roger Fisher of the LTOT, and to the former HWS Associates LLP (now Taylor-Hammond Associates Ltd) [3] and Lucien Nunes [4] for permission to use information here which has resulted from their work at Battersea.

Some Historical Landmarks

Although this is not a biographical article, some important landmarks which figure within its timeframe of interest nevertheless need to be mentioned to set the scene.

For some years until 1886 when there was a dispute with the vicar, Hope-Jones had been the organist and choirmaster at St Luke's church, Tranmere, a township on the outskirts of Birkenhead facing Liverpool across the river Mersey. One of the issues which apparently caused the rift was that Hope-Jones had personally funded the acquisition and installation of a second hand organ for the then considerable sum of £359, and he himself had set it up in the church. This is mentioned because some commentators maintain that this organ at St Luke's was the first to be built by Hope-Jones using his novel electric action, which is not the case because it was and remained a tracker action instrument. However the St Luke's story demonstrates his early interest in practical organ building, and there is some anecdotal support for experiments he undertook on electropneumatic key action at this time. These matters are described in engaging detail in Roger Fisher's book already mentioned [5].

Following the débacle at St Luke's, Hope-Jones (complete with choir) transferred his loyalties to nearby St John's church at Birkenhead in 1886. Together with the Liverpool organ builder Franklin Lloyd, he rebuilt the existing organ and the resulting instrument is properly regarded as his first foray into building organs with an electric action. Largely complete by 1888/89 while he was still employed as a telephone engineer, the organ was controlled entirely electrically, the tilting-tablet console was detached and small enough to be readily moveable and it was blown by a town gas engine which also drove a dynamo providing power for the electric action. These issues are important in the context of this article and they will be returned to later. A more detailed description of this organ is in Appendix 1.

In 1889 Hope-Jones resigned from the telephone company and in 1892 his first company, the Hope-Jones Electric Organ Company Ltd, was formed. The same year he was elected to membership of the Institution of Electrical Engineers as it was then known (now it is the IET). During the intervening three years he enjoyed the support of some influential backers, particularly the wealthy Liverpool brewer Thomas Threlfall. As a result he had access to venture capital which funded his early activities on a number of fronts – some patents on electric action were granted [6] and he gave an important lecture to the College (later the Royal College) of Organists in London [7]. He also published a pamphlet [8] describing his electrical system which included testimonials from many organ builders, some of whom had already begun using it under license. Unfortunately none of this material contained sufficient detail to enable anyone skilled in the art to verify many of Hope-Jones's claims, let alone to reproduce his results. On the contrary, careful and objective reading reveals his appetite for propagating misinformation at best and downright untruths at worst. An example is the many claims that his action magnet consumed far less power than those of his competitors (in fact it consumed far more), thus leading to the fiction that his largest organs would run for long periods on a dry cell [9].

In 1895 the company folded, to be followed by three others which likewise came and went within the next eight years. This did not prevent the construction of several large and famous organs such as those at Worcester cathedral (1896) and Edinburgh university's McEwan Hall (1897). Many smaller instruments were also built including some tiny ones with only a single manual, yet even these had a diaphone rank! At the same time other builders continued to install organs which can be reasonably regarded as Hope-Jones clones because they used his patented components and techniques under license. Towards the end of his sojourn in Britain Norman and Beard, one of the most enthusiastic builders of cloned instruments, erected a large four manual concert organ in Battersea Town Hall (now the Arts Centre) which was inaugurated in 1901 by Hugh Blair [11] though it was not paid off until 1903. Blair had formerly presided at the monumental Hope-Jones instrument at Worcester Cathedral. The contract was originally intended for one of Hope-Jones's transient companies and he was retained for a while by Norman and Beard in a consultancy role after its collapse, though the relationship soon soured. Because this organ still existed in largely its original form prior to the fire of 2015, and because it was then being restored, it was possible to extract much relevant information for the purposes of this article when it was first drafted in 2009.

These two organs at Birkenhead and Battersea more or less mark the beginning and end of Hope-Jones's activities in Britain in terms of his early and mature organ building practice respectively. In the intervening period can be found evidence of the ways his thinking and practice evolved regarding organ actions, and these are examined in the remainder of this article. When he left for America in 1903 he took these concepts with him and they underpinned his subsequent work, including that which eventually led to the Wurlitzer theatre organ.

Generic Issues

This section deals with several issues relevant to Hope-Jones's key, stop, coupler, swell shutter and combination actions. Most of them used his electropneumatic action magnet in one way or another and virtually all of them involved electrical contacts, which had to be reliable. Therefore these and related generic issues will be discussed first.

As an elected member of the Institution of Electrical Engineers, Hope-Jones came to organ building from a professional electrical engineering background unique to all his competitors. It is therefore unfortunate that too many commentators have since taken pleasure in sneering at a mere telephone engineer having had the audacity to enter the hallowed trade of building church organs. Several generations of telegraph engineers since about 1830 had already laid the foundations of sound electromagnet and electrical contact design in telecommunications practice, which Hope-Jones had absorbed and which he later applied to electric actions in organs. Many of these are details which are not immediately apparent to the uninitiated, and even today they can only be appreciated by a careful examination of his components and techniques by those with the necessary expertise and objectivity. Most organ builders of his day, and many since, either ignored or never understood these essential nuances which are indispensable to a successful electric action. I have expanded this theme elsewhere [12], and this section of the article now examines it with special reference to the work of Hope-Jones.

Contact design

The design of reliable contacts involves far more than merely having a couple of bits of metal touch each other. Some of the issues (environment, enclosure, materials and mechanical aspects) have been covered in [12] and the discussion will not be repeated here. Instead, two additional topics will be discussed – contact resistance and redundancy – because it is obvious from his legacy that Hope-Jones understood their importance to achieving good results. It is interesting that the contacts still used in high quality switches and relays today employ similar techniques to those used by Hope-Jones in his organs. He did not invent them of course; by 1890 they had become part of the stock in trade of a professional electrical engineer because their roots can be traced to the earliest development of the electric telegraph. The point is that he was the first to introduce them routinely into organ building, though others frequently ignored them or misunderstood the importance of what they saw as irrelevant details. This continues today as we shall see.

Contact resistance

Figure 1. Two common contact configurations

Figure 1 shows two common contact configurations. That on the left is a pair of domed contacts as commonly found in relays for example. On the right is a wire arranged to contact a wiper or busbar running perpendicular to the plane of the diagram. This type is frequently used for organ key contacts, or in the ladder switches used for coupler relays. In both cases minimising contact resistance is important to minimise voltage drop, and moreover the resistance must be stable over long periods and several tens of thousands of operations. In the case of a good quality commercial switch or relay contact resistance is typically a few milliohms.

Contact resistance is a function of the area of the parts which touch, and in turn this is a function of the force applied to bring the parts together. This can be appreciated by looking at the wire and busbar example above in which the contact area is small (it would be infinitesimally small for a perfectly cylindrical wire and busbar). This leads to an intrinsically high contact resistance unless we do something about it, and what we do is to bring the parts into contact with a definite amount of force, an amount chosen explicitly at the design stage. Initially the pressure between the contacts is high because the applied force is exerted over a very small area, and this causes elastic deformation of the metal surfaces by a small amount which depends on the value of the force. While the force is applied it therefore temporarily increases the contact area and thus reduces the contact resistance to the required value. When the contacts separate the surfaces return to their original shapes.

The brief description just given conceals the breadth of an important topic in electrical engineering to which considerable resources are still devoted, though it gives a flavour of the issues involved. Other factors relate to the dispersal of dirt and surface contaminants, and here again the amount of applied force is important. A force of several tens of gmf is typical for commercial relay contacts in small-signal applications which switch currents below one ampère or so. But here resides a historical problem for organs. Organ builders seem to dislike key contacts which materially affect the weight of touch set by the key spring (typically around 100 gmf), therefore the contact blocks are frequently designed, and arranged with respect to the key leverage, such that the contact force is too low. The problem also occurs in coupler relays using ladder switches in which a single magnet pulls a stack of some 61 wires into contact with the same number of busbars. If the magnet is a beefy one which exerts a pull of, say, 4.5 N (about 0.45 kgf or 1 lbf, typical of a "heavy duty" lever magnet) then the force between each pair of contacts will only be around 7.5 gmf. Using smaller magnets will exacerbate the problem still further. Forces of this order are far too low, and it explains why these switches have historically been so unreliable and why they remain so today.

Did Hope-Jones appreciate the problem and did he overcome it? The answer is affirmative in both cases. For example, he used two methods to ensure sufficient force could be applied to the contacts in his coupler relays (ladder switches). Firstly he operated them electropneumatically rather than directly by an electromagnet, thus by using a pneumatic motor of suitable size he could apply as much force as necessary to the contact stack. Secondly he employed a rotary rather than a linear actuator for bridging the contacts as sketched in Figure 2, and a photograph of an actual Hope-Jones relay cabinet is shown later. This meant that the force required of the motor depended on the total *frictional force* between the contacts and their bridging pins, rather than directly on contact force itself. If properly designed and set up, the frictional force could be made lower than the contact force.

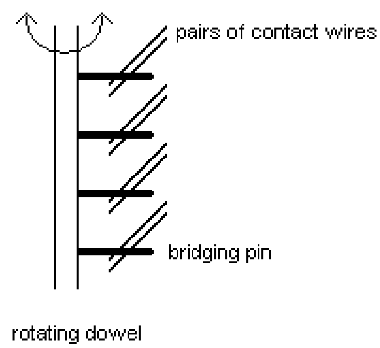


Figure 2. A Hope-Jones coupler relay: rotating actuator arrangement

Unfortunately this neat trick seems to have been virtually forgotten since Hope-Jones's day except in a few cases - not surprisingly, Wurlitzer went on to use a similar technique in their theatre organs, which in any case was a direct result of their having employed him in the first place. Compton was one of many builders which did not and their ladder switches were inconveniently, sometimes embarrassingly, unreliable. Not only did they use linear actuators (in the form of paxolin traces) but they were operated directly by lever arm electromagnets which were far too small for the job. Apparently aware of the resulting reliability problem, they sometimes duplicated entire relays for important couplers (such as unison offs) in an attempt to mitigate it. The same fundamental design mistakes are still obvious for all to see today in most of the ladder switches available from organ supply houses.

Contact redundancy

It is easy to improve the reliability of contacts merely by including redundancy in the form of duplication. For example, instead of using a single contact wire, a pair of wires will always improve performance by a significant factor. Simple probability theory demonstrates this – consider a case in which a single wire-and-wiper contact has a one in four chance of failing on average, in other words it would have a 75% chance of working. This would be unacceptable for organ applications because it would mean that if you pressed a key four times in succession, on average you would get no response in one case. Yet by using two wires instead of one the probability would rise to nearly 95%. This means that a pair of unacceptably bad contacts will become nearly infallible when operated together. The reason is simple of course – using two wires means that the probability of both failing to conduct *at the same time* is lower than that for each wire separately.

Redundancy of this type is still used in high quality switches and relays, and the example in Figure 3 is a sketch of a bifurcated relay contact as used for well over a century in telephone exchanges and other applications.

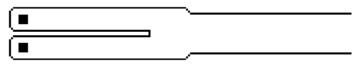


Figure 3. Contact redundancy: bifurcated relay contact

Hope-Jones employed redundant contacts in several of his organ mechanisms, one type being simply an elongated wire loop as shown in Figure 4. These provided two contact points between the wire and wiper instead of just one, and he used this configuration in several switching applications.

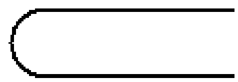


Figure 4. Contact redundancy: simple wire loop configuration

Wire loops were found frequently in Hope-Jones's key, pedal and piston contacts (e.g. at St Modwen's, Burton upon Trent) and in the changeover (single pole double throw) switches used in the power saving mechanism which he applied to his double-acting slider machines (e.g. at Battersea Town Hall, described in detail later). He also implemented the same power saving scheme in his double-acting electropneumatic coupler relays. These also are described in more detail later, but a photograph of the changeover switches in those in the organ at St Paul's, Burton upon Trent in 1894 is shown at Figure 5. As with his contact resistance reduction techniques already described, such apparently simple elaborations were frequently overlooked by other organ builders who saw what Hope-Jones had done but were unable to appreciate their importance.

Figure 5. A Hope-Jones coupler relay using wire loop contacts
(Copyright © Lancastrian Theatre Organ Trust)

Magnet design
Hope-Jones's ubiquitous action magnet or electromagnetic valve was used as the first stage of his multi-stage electropneumatic actions and it played a pivotal role in all of his organ mechanisms – he applied it to his key, coupler, speaking stop, swell shutter and combination actions. So it is discussed at this point in a generic sense in view of this universality. It was first announced in his early patents, though in prototype form somewhat more primitive than the sophisticated mass-produced items which were embodied in their thousands in his organs only a few years later, and examples of these can be seen in Figure 11. Today's action magnets are still based on the design principles developed by Hope-Jones some 130 years ago as of 2020, and this familiarity should not blind us to their subtleties which have not been bettered since.

It is clear from those found in surviving organs that Hope-Jones had devoted much theoretical and experimental effort to the design of his disc valve action magnet, and here again we can discern the part played by his engineering background. He described it in British patent 15461 in 1890, so this early development work must have taken place well before he resigned from his telephony career in favour of organ building. As with many patents, those of Hope-Jones usually contained not quite enough information to enable readers skilled in the art to reproduce his results, together with a sprinkling of irrelevant material to send them on a wild goose chase. I have discussed this patent elsewhere (see Appendix 1 in [9]), and will now take the analysis further.

Electromagnet basics
From an electrical point of view only (i.e. ignoring magnetic aspects such as intrinsic versus effective core permeability, core cross-sectional area, hysteresis, saturation, remanence, etc) two of the most important parameters of a DC electromagnet are the number of turns of wire on the coil and the current flowing through it. The greater the value of either, the more powerful the magnet. They are often combined in the idiomatic and convenient electrical engineer's unit of the "amp-turns" product for a particular magnet. For those who prefer nobler names, this product is related to the magneto-motive force of the magnet. Therefore the applied voltage only affects the force available from a magnet in the secondary sense that it defines the current passing through a coil of given resistance. In turn, coil resistance is influenced by the number of turns and the wire diameter.

There are several ways to design an electromagnet, but often one first needs to know how much physical space is available for the coil. Standard formulae developed in the 19th century then enable one to trade wire diameter against number of turns to fill the space, giving the coil resistance at the same time. For example, if there is not much space for the windings then one would have to use finer wire for the same number of turns than if more space was available. This will result in a higher resistance, demanding the use of a higher voltage to achieve the necessary current and thus the same amp-turns value. Thus electromagnet design is as much the art of juggling the various interacting parameters as it is a science, and in its history since the electromagnet was invented in 1823 by William Sturgeon (who, interestingly, had friendly links with an organ builder) there have arisen various rules of thumb and tricks of the trade. It is difficult for one without the know-how to come to magnet design and have one's first attempt work properly (I speak from experience), and we therefore have to respect Hope-Jones's abilities in these matters. Electromagnet design is something he had in his blood as a telephony engineer whose life was dominated by relays, coils and magnets of every description. This is not sycophancy but a judgement I have reached having investigated what he did in the detail unfolded in this article.

However the magnetic circuit of an electromagnet is just as important as the electrical aspects just summarised. Having designed a suitable coil for a given operating voltage as above, a low-remanence core material such as soft iron must be chosen so that it does not saturate when the power is applied. Saturation would mean that the efficiency of the resulting magnet in terms of its pulling force would cease to increase as the coil current was increased. On the other hand a magnet should be designed so that the amp-turns product of the coil takes the core near to saturation, otherwise efficiency will be squandered. The choice of core goes beyond the material employed since it involves parameters such as effective magnetic permeability and its dependence on core geometry among other factors, and it is a subject which cannot be taken further here. But having made an electromagnet, its efficiency (pulling force) then depends strongly and inversely on flux leakage. In simple terms, the lines of force which the coil generates within the core (the magnetic flux) has to be confined within a magnetic circuit of some kind, which must be designed so as to minimise its escape. Flux leakage results in reduced pulling force for any magnet. The closed physical magnetic circuit of Hope-Jones's magnet was formed by the hairpin configuration of the core and the small lightweight disc valve close to its poles. Yet even though the circuit might be closed, flux can still escape at physical gaps such as that between the pole pieces of the magnet and the armature. In the case of Hope-Jones's magnet the armature was the disc valve itself which acted as a two-way pneumatic switch, deflecting pressurised air either into a primary pneumatic relay motor when the magnet was not energised or allowing the motor to exhaust to the atmosphere when it was energised. In the latter case the disc is drawn onto the magnet poles, so there is little flux leakage because there is little or no physical gap in the magnetic circuit. In this condition of low flux leakage the attractive force between magnet and disc is maximised. But when the magnet is not energised the disc is blown onto the exhaust tube above the poles by wind pressure, resulting in a gap in the magnetic circuit and thus in flux leakage when power is applied. Re-energising the magnet in this 'off' condition will only result in valve movement if the magnet can exert a force on the disc greater than that due to the wind pressure holding it against the exhaust tube. For reliable operation the force must be significantly greater in practice than this minimum value.

Therefore the force required to pull the valve off the exhaust tube is the critical parameter in designing this type of magnet, and this depends on the wind pressure used. However the force actually exerted on the valve by the magnet varies as the cube of distance between the poles and the disc for Hope-Jones's hairpin design, being greatest when the distance is zero (when the disc is drawn onto the poles) and least when the disc is occluding the exhaust tube. Since a cubic force characteristic varies strongly with distance, it follows that the gap between the magnet poles and the exhaust tube has to be minimised if the electrical power consumption of the magnet is also to be minimised, otherwise a low power magnet will not work at all if the gap is too large. At the same time the gap must be large enough to allow a sufficient windway to exist in both the energised and unenergised states. It is this logical path which Hope-Jones must have followed when he was designing his action magnet, and which led him to his chosen valve operating clearance (the disc movement) which he preset by careful adjustment of the threaded exhaust tube. He claimed frequently that the valve moved by only 1/64th of an inch (roughly 0.5mm), though there is anecdotal evidence that this was exceeded once sufficient experience had been gained with the production magnets.

Windway augmentation – the "pepper pot"

Even by the understandable reprographic norms of the day the illustrations in Hope-Jones's magnet patent were scrappy and of a rather poor standard; one suspects this might have been deliberate. Nevertheless we can extract some useful information by studying the sketches reproduced here in Figure 6a. Firstly we see that Hope-Jones used a two stage pneumatic force amplifier following the chest magnet in his electropneumatic actions, which in itself is not remarkable. The additional drawing on the right of the magnet alone conveys little additional information. The two illustrations on the left are of most interest because they reveal the "pepper pot" attached to the exhaust tube of the magnet. Note that usage here of the name "pepper pot" is mine, having been introduced many years ago in previous versions of this article. This is mentioned because the term has now become widely used when discussing Hope-Jones's action magnets, though sometimes in an incorrect context. The pepper pot, for obvious reasons, refers only to the internal perforated valve seat illustrated in Figure 6a, not to any other component of the magnet such as the external fluted dust cover which can be seen in Figure 11. An actual example of a pepper pot in the Hope-Jones/Norman & Beard organ at Battersea Town Hall is shown at Figure 6b.

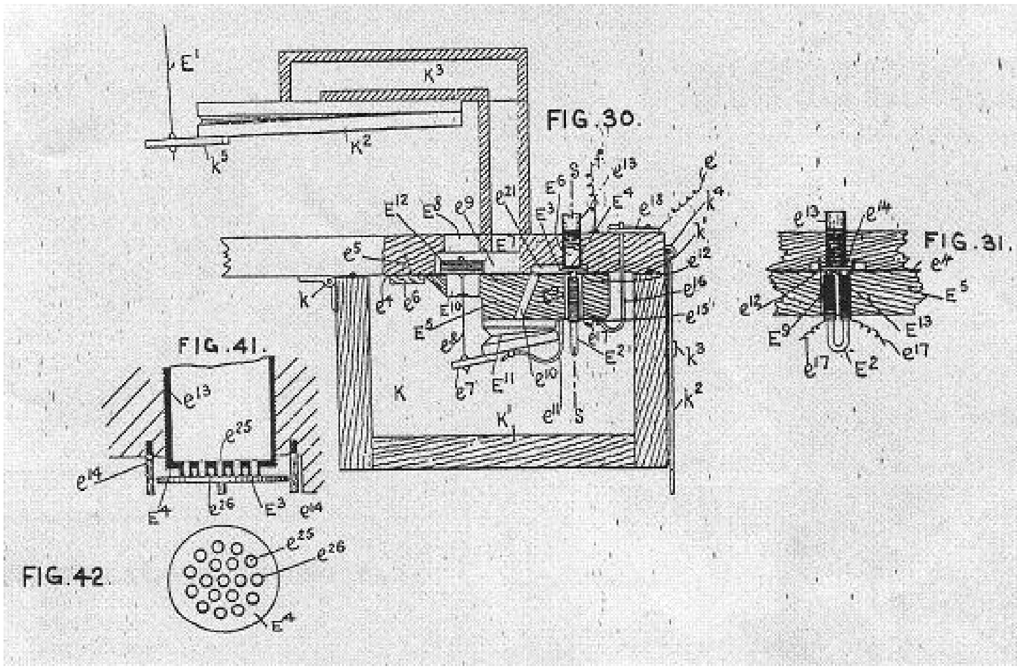


Figure 6a. Extract from Hope-Jones's patent 15461 (1890)

Figure 6b. A "pepper pot" exhaust valve seat (Battersea Town Hall organ)

(Copyright © Lucien Nunes)

Of the few authors who have commented on it at all, such as Audsley [14], most seem to have assumed that its sole function was simply to reduce the force required to pull the disc valve away from its seat against the multiple orifices of the pepper pot. This conclusion is obviously baseless if one thinks about it, because there can be no difference between the force exerted on the valve as shown and one which covers a narrower exhaust tube with the same total cross sectional area as that of the multiple pepper pot tubules. In other words, if you merely want to reduce the force, why not just use a narrower exhaust tube rather than the complication of a pepper pot? It would have been a precision item of engineering and therefore difficult and expensive to make. The fact is that Hope-Jones saw the pepper pot as a device which would increase the windway of the disc valve and simultaneously reduce the force needed to open it, a technique already used elsewhere in Victorian fluid control technology such as in steam, hydraulic and gas engines. This will now be demonstrated by an analysis which, though straightforward, neither Hope-Jones nor anyone else to my knowledge has published before for organ applications.

The windway W_1 of an ordinary disc valve (no pepper pot) is the surface area of the cylinder described by the valve as it opens. This is given by

$$W_1 = \pi Dm \qquad (1)$$

where D is the internal diameter of the exhaust tube and m the amount by which the disc moves.

For the array of tubules of the pepper pot, their total windway is given by

$$W_2 = N\pi dm \qquad (2)$$

where N is the number of tubules and d their diameter ($d << D$).

Taking the drawing in Figure 6a at face value there are 18 tubules, a figure confirmed by the actual example shown in Figure 6b, thus $N = 18$. Making approximate measurements from the diagram, their internal diameter is about 1/13th that of the exhaust tube, thus $d = D/13$. The exhaust tube in Hope-Jones's magnet was somewhat wider than those used in similar chest magnets today and it had an internal diameter of about 8mm. Therefore the diameter of each tubule would have been about 0.6 mm.

Putting these values into equation 2 gives a value for $W_2 = 1.4\pi Dm$ approximately, therefore $W_2 = 1.4W_1$. This demonstrates the effectiveness of splitting up a single aperture into a number of smaller ones in that the windway has been increased by some 40% in this case for the same valve movement. In reality it is likely that the improvement will not be as great as this because one has to take into account the restriction to air flow through the narrow tubules. It is also important to note that the arrangement will not work as desired if the tubules do not stand sufficiently proud of the baseplate from which they project; it would not be sufficient simply to drill an equivalent number of small holes in the baseplate. The tubules must project by a distance greater than the amount by which the valve moves if there is to be no additional throttling effect due to the air having to flow through the narrow gap between the baseplate and valve disc.

As well as increasing the windway of the valve, the total exhaust area of the tubule array has been reduced by a factor of about ten compared to that of a single exhaust tube, assuming the same values for *N* and *D/d* as above. Thus the force required to operate the valve against the wind pressure will reduce by the same factor because force is proportional to valve exhaust area in both cases. On the face of it these twin advantages of significantly increased windway and massively reduced operating force are therefore compelling ones.

As just remarked, Hope-Jones did not invent this technique although he was presumably the first to suggest applying it to organs otherwise his patent could have been invalidated subsequently. I do not know how widely he employed it in practice as I have not personally come across one of his chest magnets which was actually fitted with a pepper pot valve seat in the form illustrated, though some of them had seats with fewer but larger sub-apertures. However examples surfaced when the organ at Battersea Arts Centre (formerly the Town Hall) was being dismantled in 2013, and Figure 6b shows one of them. They were not in universal use throughout that instrument because some other magnets were of the fewer-but-larger tubule pattern mentioned above, whereas yet others had no specialised valve seat at all beyond the cylindrical exhaust tube itself (which is of course the simple form used today). From a practical point of view, apart from the cost of manufacturing such a small item of precision engineering, the narrow tubules would easily have become blocked by dust and dirt. Moreover, as mentioned already, the theoretical windway augmentation factor might have been reduced in practice because of resistance to air flow through the assembly even in the absence of blockages. Therefore Hope-Jones or others who built to his system might have decided it was more trouble than it was worth for reasons other than manufacturing cost, because if there is not a significant windway augmentation effect in practice then there is no point using it – disc valve operating force on its own could be reduced more easily just by using a narrower exhaust tube to start with.

As conjectured in the previous article already referred to [9], I still harbour a suspicion that the pepper pot might have been one of those red-herring ideas which one often finds in patents – nothing that was claimed was actually incorrect, but the things which were not said were more important. Though the discovery at Battersea shows unequivocally that Hope-Jones did use it on occasion, the fact that it was not employed throughout that instrument suggests that its merits were not overwhelmingly important – its absence was obviously not a show stopper. But any organ builder who thought it was a vital and indispensable part of Hope-Jones's magnet would probably have been dissuaded from plagiarising any other elements of the design, and this would have suited his purposes just fine. He must have had a very good patent attorney, which is likely if only because his venture capitalist Thomas Threlfall was paying the bill!

Why did he even consider using such a complicated pepper pot magnet design at all? By the time you have finished reading this article it will have become apparent that Hope-Jones worked hard to minimise the power consumption of his organs, mainly so that they could work reliably on batteries for limited periods. Although he used dynamos whenever he could, as in his first prototype instrument at St John's, Birkenhead, these would have required blowing plant powered by mains electricity, high pressure water or town gas which much of the country simply did not have access to. So his action magnet was designed in the first instance to work at low power, which meant that it could only reliably pull in an armature - the disc valve - by a small amount against the wind pressure, with 1/64th of an inch (roughly 0.5 mm) being the figure he often bandied around. In turn this explains why he felt compelled to investigate means for reducing the operating force and increasing the windway of these sensitive electromagnetic valves. But although this logic is unassailable, experience amassed subsequently by those who actually built organs using his system suggests that the magnets could be simplified without sacrificing performance. We see this from the Battersea organ which, although it used some pepper pot type valves, also used much simpler ones with no special valve seat technology at all

Magnet resistance and operating voltage
In his writings and utterances Hope-Jones laid emphasis on the need for a high magnet resistance to prolong battery life in those cases where his organs were thus powered, and in this he was merely echoing what other organ builders said at the time. However there was in reality a gulf between them – whereas other builders did indeed use high resistance magnets of several hundred ohms, Hope-Jones did not [15]. It is in fact quite difficult to discover the resistance he favoured from the prose in his patents for example, where he took refuge in vague phraseology such as "many turns of fine wire leading to a high resistance", but I am now of the view that it is probable he seldom or never used resistance values over 100 ohms. He would have understood the dangers of being too open in this area when he was claiming, dishonestly and disingenuously, that his action magnet consumed far less power than any which had gone before. The dark secret was kept so well that people usually believed him and some still do, though to his credit Audsley was an exception [14]. In fact the resistances of his surviving magnets are most often in the region of 50 to 60 ohms, though some exhibit a higher figure. At this remove in time it can be difficult to know whether a magnet one is presented with is in its original form or has been rewound to have a different resistance.

The required operating voltage likewise varied somewhat. His most extravagant and frequent claim that his organs would work on 1.5 volts from a single dry cell was a fiction and can be discounted [9]. At the other extreme it is probable he did not use more than 8 volts, the voltage generated by the dynamos mentioned in his surviving shop notebooks [19]. All his actions and other mechanisms which used his 50 ohm action magnet would have generally worked pretty well on 6 to 8 volts and this is backed up by some recent experiments mentioned later. This is not surprising because it fits nicely with the amp-turns product for the several variants of this type of magnet which have been used by organ builders worldwide over the last century or so. Components rated at 6V/50Ω (Hope-Jones), 12V/100Ω (typical of the mid-20th century) and 15V/150Ω (a typical value today) are all similar in that they consume 100 – 120 mA and have a comparable number of turns on their coils.

Magnet efficiency
By magnet efficiency I mean the force exerted by a given electromagnet for a given value of direct current passing through its windings. As a former telephone engineer, Hope-Jones would have known that efficiency was strongly related to flux leakage as discussed already. We saw that minimising flux leakage means that the magnetic circuit has to be complete (hence his use of a hairpin configuration so that the flux

from both poles was returned to the armature and passed through it), and air gaps in the magnetic circuit had to be minimised (hence the armature movement had to be minimal while still enabling it to do its job).

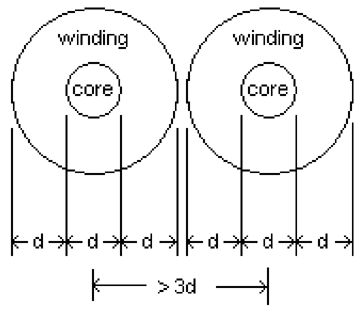


Figure 7. Magnet geometry for a hairpin electromagnet

Another design issue influencing magnet efficiency concerns the maximum coil diameter. You cannot go on adding layers of wire *ad infinitum* even if you have the space, because the further away the turns get from the core the less efficiently the flux they generate links with the core. This represents another contribution to flux leakage and thus to a reduction in magnet efficiency. The electromagnet was invented in 1823 and early on it seems a rule of thumb developed that the maximum winding depth should not exceed the diameter of the core if flux leakage was to remain within reasonable bounds. This is illustrated in Figure 7 which is a sketch of the geometry of a hairpin electromagnet looking onto the poles, in which *d* is the core diameter. Therefore the poles cannot be closer than about 3*d* if one wants to use the maximum amount of wire.

Factors such as these must have led Hope-Jones to develop his action magnet in the form he did, including its adjustable exhaust tube to set the valve movement accurately. His basic design was so sound that it is still used to this day with little modification.

Measurements on several surviving magnets used by Hope-Jones and others in organs built over the period covered by this article show that they would typically just pull in a properly adjusted valve with a current of about 50 mA against a wind pressure of 150 mm wg (6 inches) [18]. Of course, in practice the current would need to be significantly greater than this for the organ to function reliably, with the figure of 100 – 120 mA mentioned above being typical.

Depolarising
Organs have to work reliably for periods measured in decades, and over this timescale Hope-Jones probably realised that it would be difficult to predict the risk of residual magnetism building up in his magnets. If this happened there would be a danger that the lightweight disc valves would adhere permanently to the magnet pole pieces, with unthinkable consequences. Thus he addressed early in his career a number of ways to prevent this, and he mentioned the topic under the heading of depolarisation in his 1891 lecture to the College of Organists [7]. However he passed on without giving further details on that occasion.

One technique he apparently considered was to send current in the reverse direction through the magnets from time to time, as mentioned in his early patents [6]. In practice the simplest way to achieve this (far simpler than the methods suggested in his patents) would have been to periodically reverse the polarity of the DC supply to the entire organ, perhaps at tuning visits. In Hope-Jones's day polarity-sensitive circuit devices such as diodes did not exist, so there seems no *prima facie* reason why he could not have used this method (unless he used polarised relays for some purpose or other, and though currently I have seen no evidence that he did, they were mentioned from time to time in his patents [6]). Nevertheless I have no knowledge whether he or his employees actually did use the polarity reversal trick, as it is merely an obvious approach which independently occurs to me. However some of his organs (e.g. that at Worcester cathedral) did suffer from the residual magnetism problem about 18 years after he had emigrated in 1903 [13], [20] so it is possible that the other organ builders who maintained it after his departure were unaware of the importance of taking preventive measures. Either that, or they had a vested interest in hastening its collapse.

Corrosion prevention, release time and spark suppression
Some of Hope-Jones's later magnets were fitted with a zinc disc surrounding the magnet poles. This was probably intended to reduce corrosion of the pole pieces in damp environments. In addition, eddy currents in the disc would have slightly increased the release time of the magnet and thereby reduced the sparking problem at the contacts. These matters are discussed further in the section dealing with key actions.

Automatic power shutoff
Hope-Jones said and wrote much about the allegedly miniscule amount of power required to operate his action magnet to the extent that his largest organs would run for months on a single dry cell. I have shown elsewhere that the claim was baseless and that, sadly, it therefore reveals him as a purveyor of blatant untruths [9]. The fact is that his magnet consumed many times more power than those of his competitors for a given voltage [15], so much so that he had to introduce means for shutting off the current automatically in his later organs. One reason for this was presumably to save power. Although this was unnecessary when he used dynamos to supply the current, it assumed importance when it was derived from accumulators or (with certain organs only) a *battery* of dry cells (not a single cell).

However there was probably another reason why he deemed it necessary to shut off the current which does not seem to be well known, and this concerns the temperature rise in his magnets were they to operate continuously. This is nothing to do with power saving but it will be discussed here for convenience.

Temperature rise in the action magnet
To appreciate why temperature rise in the magnet was a potential problem we first need to know what type of wire Hope-Jones used in his magnets and how it was insulated. Today we simply buy so-called "enamelled" copper wire when we want to make an electromagnet and it is easy to overlook the difficult and protracted birth pangs of this essential material [16]. In fact today's wire is not enamelled in the Art Nouveau sense at all, rather it is covered with a thin but tough modified polyurethane

coating which is not easily removed or damaged mechanically. However it is easily and conveniently burnt off by the heat when soldering it.

Wire enamelling techniques did not become good enough for routine use in electrical engineering until well into the first decade of the 20th century, which was after Hope-Jones had emigrated to America. Prior to that it was necessary to use cotton or silk covered copper wire for bells, telephones, transformers, motors, dynamos, relays and other sundry electromagnet coils, a technique originally introduced by Michael Faraday many decades before. However it was far from ideal because even the thinnest fabric covering was too thick when it was necessary to cram as much wire into the winding space as possible, and it was frequently eaten by moths and rodents which is why magnet wire was often coloured green or blue in equipment from that era by impregnating it with repellent. The insulating properties were poor especially in damp conditions. Even when dry, silk or cotton could be penetrated easily by high voltage sparks within the windings and once this had happened the entire coil could rapidly become useless. This problem potentially afflicted Hope-Jones's magnets because he had limited means at his disposal for suppressing the high voltage surge which occurred when the circuit was broken.

From the outset, therefore, Hope-Jones impregnated his coils with wax or shellac-based varnish which would soak into the fabric covering to prevent it absorbing moisture, to provide some protection against high voltage breakdown and to resist moth and rodent attack (although certain rodents are apparently attracted by wax). This was a standard technique of the day. Unfortunately it brought with it the consequential problem that the coils could not be allowed to heat up, otherwise the varnish or wax would run out. This was at a time when wax products would almost melt and French-polished furniture would become tacky on hot days. His magnets consumed typically one watt at their operating voltage around 7 volts, not a lot in an absolute sense but enough to cause them to warm up when energised for long periods. For this reason, as well as economising on power, Hope-Jones was driven to incorporate means for shutting off current to as many magnets as possible in his organs while they were not actually performing a function. Interestingly, one of today's organ builders came across this problem recently when the Usher Hall organ in Edinburgh (Norman and Beard, 1914) was being restored by Harrison and Harrison in 2000. Norman and Beard often used Hope-Jones's components and techniques, and Harrison's expressed regret that they felt unable to retain what they referred to as "these handsome components" (i.e. Hope-Jones's action magnets) because of their wax insulation and consequential overheating risk [17].

In summary, throughout the 19th century and into the 20th the best efforts of electrical engineers on all fronts were hindered by the problem of inadequate insulation. Hope-Jones was no exception, and it is likely that insulation breakdown in his electromagnets was responsible for at least some of the failures of his organs. After a quarter of a century of service the action of that at Worcester cathedral more or less collapsed, in part because of "perished insulation" (Arthur Harrison's words) and burnt wiring [13], though I would like to establish whether a lightning strike played a role in this before jumping to conclusions. Whatever judgements are reached, one must not blame Hope-Jones for his inability to solve problems that were insoluble at the time, especially as all other organ builders who used an electric action faced exactly the same challenges.

Power supplies
Hope-Jones and those building clones of his organs under license used dynamos, rechargeable secondary cells in the form of lead acid accumulators and (occasionally) non-rechargeable primary batteries comprising wet Leclanché cells or dry cells to power their actions. It is important to realise that Hope-Jones's organs fell into two categories as far as power supply considerations were concerned – those which used an electromagnetic (direct electric) action for moving the stop tablets in response to the combination pistons, and those which used an electropneumatic action. Both will be described in more detail later. There it will be shown that his electromagnetic stop action magnets would have drawn a current of about one ampère each from a 6 volt supply, whereas when operated electropneumatically they would only have needed about 120 mA. Thus moving many stops on or off simultaneously in response to a piston meant that peak currents of many ampères would have been required in the former case.

This high peak current requirement for an electromagnetic motorised combination action meant that only dynamos or accumulators could have been used to power the organ in question, because only these have an internal resistance much lower than the load resistance. Typically their internal resistance would have been, as now, a few tens of milliohms or less. On the other hand the internal resistance of a dry battery is at least ten times higher, and moreover it rises as the cell ages or discharges. A typical value for a battery of three or four cells would have been, as now, at least 0.5 Ω. This limits the maximum current which can be drawn from a dry battery to a few ampères before its terminal voltage drops to a level below which the magnets will not work, thus rendering it completely inadequate to power an electromagnetic combination action.

From the outset Hope-Jones showed by his practices that he preferred to use dynamos whenever he could despite ridiculous claims that his organs would run on a single dry cell. His first organ at St John's, Birkenhead used a dynamo [7], [23], [24] even though he himself loudly trumpeted the dry cell myth in relation to this instrument [7], [9]. The dynamo here was driven by the town gas engine used for blowing the organ, said to be by the Otto firm [21]. Otto was a well known engine maker of the day, and reading the Victorian engineering literature suggests to me that the name might have been a generic one for any type of gas engine in much the same way as we in the UK use "hoover" today to mean a vacuum cleaner. In fact Otto engines were larger and more expensive than some other types, one of which was known as the Bisschop engine. A firm in Stockport, not far away from Hope-Jones's early stamping ground, made Bisschop engines for organ blowing purposes among other things [25]. An example of the latter, now back in Manchester near to where it was made, is shown in Figure 8.

The Lancastrian Theatre Organ Trust has recently uncovered fascinating evidence showing that Hope-Jones was well acquainted with a certain Henry Royce in the 1880's, he of later Rolls-Royce fame, and that Royce's company manufactured some electrical components for Hope-Jones around that time [2]. The phrase " ... *Electro Magnetos for the Hope-Jones organ manufactured at Birkenhead* ... " occurred in an inventory of early items manufactured by Royce compiled by his company secretary John de Looze. The meaning of the term "Electro Magnetos" is unclear to me as it could refer either to Hope-Jones's electromagnets or to the dynamos he used to power his actions, or both. Royce was apparently making similar items (possibly including magnetos?) for the fledgling automobile industry either then or soon afterwards. Nor is it clear whether the "Hope-Jones organ" mentioned means solely the prototype instrument at St John's, or the several manufactured later at Hope-Jones's first factory at Birkenhead in 1893. Notwithstanding these uncertainties, there seems little doubt that Royce was intimately connected with the electrical side of Hope-Jones's early organ building activities.

Figure 8. A Bisschop town gas engine of 1882
(Copyright © Colin Pykett)

This engine was originally made in Stockport and is now in the Museum of Science and Industry in Manchester. It delivered "1.5 man power" and could be "managed by any boy or girl" - a chilling echo of those dark, Satanic mills. Note the dual belt-drive pulleys, one of which could have been used to drive a low voltage dynamo as at St John's, Birkenhead, while the other worked the bellows crank.

Thus the dynamo at St John's, Birkenhead is said to have been made by Henry Royce and to have delivered 4.5 VDC [2], comparable with the voltage from three dry cells, though this seems on the low side in my opinion given that the magnets will not work at all below 2.5 V or so as mentioned already. Later dynamos used by Hope-Jones apparently provided around 8 V [19] which appears more reasonable especially if it refers to the off-load voltage, which would then reduce slightly when loaded. This would bring it closer to the figure of 6 V (on load) which fits nicely with the various analyses presented later in the article and with Hope-Jones's practice elsewhere. The current-delivering capability of these dynamos is unknown to me, but it would have had to be in the region of several tens of ampères to power the Birkenhead organ with its (presumed) electromagnetic combination action. Combination actions are considered in detail in a later chapter.

When dynamos could not be used, such as when an organ was hand pumped because of the absence of mains electricity, gas or hydraulic power, Hope-Jones generally used accumulators, re-chargeable lead-acid cells. Such an instrument was installed at Pilton in 1898 [26] and in the 1990s anecdotal accounts were retailed to me of the accumulators there having to be recharged at the local garage as late as the 1920's.

Shown in Figure 8 is a lead-acid accumulator from the 1920's. The one pictured was sold for "wireless" purposes (heating the valve filaments in early radios) and it delivered 2 volts with various storage capacities related to physical size, 20 Ah being a typical middle of the range figure. The accumulators available to Hope-Jones would have been similar to this, although they benefited from subsequent development particularly during the first world war. A battery of three or four suitably sized cells in series would probably have powered the actions of any of his organs reliably for a few weeks before recharging.

The terminal voltage of an accumulator does not vary much during its discharge cycle apart from a rapid drop from about 2.3 V to 2 V just after being freshly charged. It also has an extremely low internal resistance of typically a few milliohms per cell which means very large currents can be drawn from it. This means that the currents of several tens of ampères demanded by an electromagnetic combination system when the pistons are used could have been provided without difficulty.

Figure 9. An accumulator cell from the 1920's

Dry cells are a completely different kettle of fish. I have already mentioned several times the absurdity of Hope-Jones's publicity scam that his organs would run on a single one [9]. Nevertheless some of them could have run for relatively short periods on a battery of four dry cells which give an open circuit voltage of about 6 V. However these instruments would necessarily have had an electropneumatic combination action, because dry cells could not have supplied the peak current demand of an electromagnetic one. Also the cells would have had to be very large with a storage capacity of at least 75 – 100 Ah. Such cells are unobtainable today (written in 2009), when even the large and very expensive 40 Ah "Flag" cell now seems to be obsolescent.

A detailed technical analysis of dry cells in relation to Hope-Jones's organs is given in Appendix 2, which presents results for the maximum number of magnets which could be energised reliably together with typical charge storage (Ah) figures for the cells. The analysis takes into account the minimum voltage required to operate the magnets, the internal resistance of the cells, circuit resistance and the fall in open circuit voltage of the cells over the discharge period. In round figures it is shown that playing simple four part harmony on a small (two manual) Hope-Jones organ for a miserly one hour per week would have required a 6 volt dry battery with a 25 Ah capacity to power the key action alone for six months. The capacity scales linearly with playing time, therefore making more realistic assumptions about the latter means that the size of the required battery would rapidly become impractical, especially for the larger instruments.

Circuits

Hope-Jones's circuits will be described extensively in later sections of this article. Here it is worth saying that they are some of the few elements of his patents which can usually be taken at face value, simply because it is easy for one with the experience to judge whether a particular circuit will work or not merely by looking at it. This is important because some of them contained errors, possibly deliberate ones. In terms of complexity and sophistication his circuits went, at a stroke, far beyond those which any other organ builder had used prior to about 1890.

The musicologists Williams and Owen have opined that "the design of circuits requires great skill and was perfected only during the 20th century" [27], but whereas the first part of their statement is correct the second part is not. Hope-Jones brought to organ electrical design the rapidly expanding portfolio of engineering techniques used in telephone exchanges, and of these the nascent science of binary logic design as implemented by switches and relays played an important role. One of his most important contributions to organ circuitry was the functional isolation concept, whereby current is prevented from flowing in unwanted circuits by using multipole switches liberally throughout the system. These were seen in his key contacts and relays which simultaneously closed several, sometimes many, circuits but which allowed them to retain their mutual isolation when open. Though this technique rapidly became commonplace it was entirely novel at the time as far as organ electric actions were concerned. The reason why this system was necessary was because there was no other means of preventing current from flowing the wrong way down the wrong conductors and thus causing unwanted notes to sound. This was different to tubular pneumatic "logic" where clack valves were used to prevent this. Semiconductor diodes, the electrical equivalent of clack valves, were components of the far future and until they became available in the 1960's the circuit techniques originally devised by Hope-Jones became the standard ones used by organ builders for decades across the world. Therefore this is why Williams and Owen were wrong to say that circuit design was not perfected until the 20th century. Hope-Jones solved all the problems in one go, big bang fashion, while Victoria was still on the throne.

Organ actions at a system level

The more one examines what Hope-Jones did, the more one comes to realise that he was a very good systems engineer as we would say today. From the outset he took a top down view of the issues presented by applying electricity to organs, dissected them into subsystems, solved the problems of each and then implemented them as an integrated working whole. This separation of the total problem into manageable chunks followed by re-synthesis back into a single entity is characteristic of systems engineering as practiced today.

In this respect he was quite different to others who applied electricity to the organ both before his time and afterwards. They tackled only one subsystem at a time, usually the key action only, and then they built organs which still retained a hotchpotch of other mechanisms for working the stop, coupler and combination actions. By contrast, Hope-Jones's first organ at St John's, Birkenhead was electrically controlled from the outset in all respects, embracing the key, speaking stop, coupler, swell shutter and combination actions. Although one must not get carried away by his achievements as others have done, it was nevertheless an impressive feat for its time. As mentioned above for his circuits, the instrument at St John's hit the organ world suddenly with a big bang. Nothing like it had been seen before.

Were Hope-Jones's organs unreliable?
A great deal has been said by countless authors about the allegedly unreliable nature of Hope-Jones's organ actions. Unfortunately many seemed unaware that they lacked the necessary technical background to make the judgement and others, particularly the anonymous ones, obviously had vested interests in other directions.

On the face of it there are aspects which might have led to some degree of unreliability. The minute amount of movement of the disc valve in his action magnet, often said by him to be $1/64^{th}$ of an inch (about 0.5 mm), does seem rather small when it would have been easy to increase it simply by unscrewing the exhaust tube a little. Such small orifices in organ pneumatic mechanism can easily become blocked by dust and dirt over the many years for which an action, quite reasonably, is expected to work. However, increasing the valve movement might have actually *increased* unreliability because the magnet might then have failed to operate the valve reliably if it was constrained to operate within the critical voltage tolerances imposed by battery operation. Whether Hope-Jones actually used these small operating clearances himself is as obscure as everything else which remains unclear about his actions because, as we have seen, there were several aspects where his motto appeared to be "do as I say and not as I do". Nevertheless, he might have decided that the increased magnet reliability that would have resulted (because of decreased flux leakage) would have been more important than long term doubts about blocked airways, which could have been prevented by proper maintenance in any case.

To my mind the apparent lack of a return spring for the disc valve, which rested on the magnet pole pieces while the organ was not in use, seems a more important feature when considering unreliability. Hope-Jones's magnets were designed for vertical mounting and his intention was that the valves would rise against gravity when the wind was applied, but this might not have happened reliably if residual magnetism developed in the magnet yoke over a long period (which it did in some of his organs). Moreover, because the valve was open when the wind was not on, all the pallets of the organ could have tried to open momentarily while the pressure was initially building up. This is a curious characteristic of his actions, though not necessarily one which would lead to unreliability. It is worth remembering that one of the few aspects of today's chest magnets which differ from those of Hope-Jones is that they do have a return spring for the disc valve. The matter is pursued in more detail in the chapter dealing with the 'master reset' problem.

There is evidence that he sometimes used unsatisfactory material for constructing his pneumatic motors. One reason for the collapse of the Worcester cathedral organ was because rubberised cloth had apparently been used [20], and at St Paul's, Burton upon Trent the wrong type of leather was the culprit [22]. However we should remember that the Worcester organ worked for around a quarter of a century and that at Burton was still going in the 1980's. So one has to adopt reasonable criteria when making the reliability judgement, and bear in mind that it is also unfair to apply more rigid standards to Hope-Jones than to other builders.

Yet another factor relates to the unfamiliarity of the general population at that time with anything electrical. Hope-Jones used dynamos whenever he could to supply the action current, but otherwise his preferred fallback solution was probably to use accumulators. However the irksome need to recharge these on a regular basis might have led some to substitute dry cells, particularly in view of the misleading and excessive emphasis which Hope-Jones himself placed on their use. The late Brian Wigglesworth spent his long career at the John Compton organ company, and from his youth he could recall some at the firm who had actually met Hope-Jones at the time when Compton was deciding which aspects of Hope-Jones's innovations to use in his own work. Wigglesworth once told me that he had come across one church which substituted dry cells for accumulators in their Hope-Jones organ because of a belief that "they would not need recharging"!

In my opinion, based largely on the extensive personal research summarised in this article, his organs were not intrinsically unreliable. All of the evidence, much of it enthusiastic from the outset, suggests they worked well when new, and some lasted until well into the second half of the twentieth century or even beyond. However they would without doubt have needed careful and regular maintenance at a time when other organ builders had virtually no experience nor understanding of electrical matters. Moreover, unless they enjoyed the unlimited power provided by dynamos, the actions of the majority of his instruments would have necessarily relied on batteries. Again, with proper and intelligent attention to this matter, there would have been few problems though. It is likely that most of the more damning accounts arose from the period post-1903 after Hope-Jones had left for the USA. By then his former properly-trained workforce was dispersed, and it is even possible that some of his instruments were subtly sabotaged for obvious reasons, though probably unbeknown to the owners [29].

The late Stephen Bicknell broadly agreed, having written the most objective summary I have seen about the matter of reliability [28], including the anonymous whispering campaign mounted in the musical press by some organ builders which became so disreputable that others rallied to Hope-Jones's defence. This led to correspondence appearing in *Musical Opinion* and elsewhere from several well satisfied customers, including the Dean of Worcester himself. Bicknell's conclusion [28] is worth repeating:

"*the fact that his* [Hope-Jones's] *instruments developed a reputation for chronic unreliability during his lifetime is probably due to malicious gossip generated by his rivals and incompetent maintenance, perhaps exacerbated by hurried or inexpert assembly when the company was under severe pressures of time and finance, as well as by a handful of design faults which could easily have been rectified*".

It seems fitting to let the matter rest there.

Key Actions

Hope-Jones used a multi-stage electropneumatic key action, usually with two pneumatic force amplifier motors controlled by his action magnet. The pneumatic aspects of the design are largely unremarkable whereas the action magnet itself exhibited a number of novel features. It performed other functions in his organs besides the key action, therefore it has already been discussed at a generic level. Its particular application to the key action will now be examined in more detail.

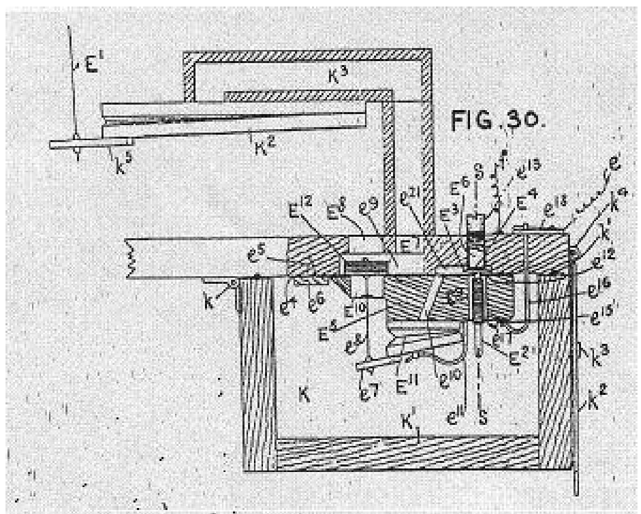


Figure 10. The key action at St John's, Birkenhead?

Figure 6a, already discussed, depicts an early form of Hope-Jones's action magnet and electropneumatic key action. The main part of the diagram is repeated above at Figure 10. It is only a sketch from a patent, so whether he actually built and used it in this form is uncertain because it is seldom that the contents of a patent specification can be taken as incontrovertible fact. However there are some interesting and rather homely practical details in the drawings which suggest they might depict a real electropneumatic organ action which was indeed made. For instance, the hinge (marked *k*) and the catch (k^1 , k^2 and k^3) which can be discerned suggest that the lower cover could be easily swung open to inspect and adjust the magnet and the primary pneumatic valve. Other little features relate to the means for connecting the fine wires of the magnet coil to the common return conductor (similar to today's "chest brass") and the wiring harness. The wood block containing the magnet and the primary pneumatic with its valve seems to be detachable as a unit, and if this is so then Hope-Jones anticipated by more than a century the compound valve only re-introduced in recent years by firms such as Kimber Allen. A further aspect is that the mechanism is in the form of a complete under-action which could have been fitted relatively easily to the soundboards of an existing organ which was being electrified, such as that at St John's, Birkenhead. It strikes me as a trifle implausible that such details, although important to the practical man who had to make up a new and unfamiliar type of action, would have been conjured out of thin air merely for a patent specification. Therefore it is at least possible that Figure 10 is a working drawing which existed prior to the patent and which depicted something that had already been made.

Proceeding on this admittedly rather fragile basis, we can note nevertheless that the magnet as depicted was nothing like the later ones (to be described in a moment) and therefore they might be regarded as the first working prototypes. Given the date of the patent (1890) and backtracking to the time when its drafting would have begun takes us neatly to the late 1880's when the organ action at St John's, Birkenhead was under construction, presumably in Franklin Lloyd's workshop in Liverpool. So can we say, perhaps, that Figure 10 is a reasonable representation of that first and famous Hope-Jones action at St John's, magnet and all?

We are on stronger ground when we look for the action magnets used in Hope-Jones's subsequent organs because many of them still exist. One of the first organs his company actually built, as opposed to those built by others under license, was that at St Paul's, Burton upon Trent in 1894 [22] and some of its mechanism plus the console now resides in the Hope-Jones museum of the Lancastrian Theatre Organ Trust in Manchester.

Figure 11. Later form of Hope-Jones's action magnet
(Copyright © Lancastrian Theatre Organ Trust)

That on the right is on the choir organ action chest from the 1894 Hope-Jones organ at St Paul's, Burton upon Trent. Note the absence of a "pepper pot" valve seat.

These later magnets appeared in the early 1890's and their design remained largely unchanged thereafter. They were very different in appearance though not in concept to the original one discussed already, and examples are shown in Figure 11. The magnet on the right with its cap removed is on the choir organ action chest from the Burton instrument. These magnets were no longer integrated with the primary pneumatic valve as in Figure 10, thus they were not compound valves in today's terminology; they were fully independent units which were good candidates for mass production. The hardwood cap could be quickly removed by rotating the turn buttons, and it held the adjustable exhaust tube which was covered by an external fluted brass dust hood. This was essential to prevent dust and dirt falling into the valve. No “pepper pot” valve seat can be seen in Figure 11, though this does not mean they were never used because apparently the valve seats of the Burton organ were modified in about 1906. The resistance of these magnets was usually around 50 to 60 ohms and they operated on about 6 volts DC.

Note the grey disc underneath the armature through which the magnet pole pieces protrude. This was of zinc and Hope-Jones said it was intended to provide protection against corrosion to prevent the poles rusting in damp conditions such as those found in churches [36]. A build up of corrosion at these points would have prevented the valve shutting off the air supply completely when the magnet was energised, and it would also have prevented the valve opening fully and thereby throttling the exhaust path as well. When zinc and iron form part of an electrical circuit, the zinc is a sacrificial anode which corrodes before the iron. However the circuit must be electrically and ionically complete for this to work effectively. While the direct electrical connection was present between the iron poles and the zinc, the ionic return path would have scarcely existed. Thus although the method works well in water (for protecting ships' hulls for example) its effectiveness in air would have been open to question.

Another reason for the presence of the zinc disc might have been to slightly reduce the rate at which the magnetic field collapsed when the circuit was broken. This would then have reduced the high voltage kick produced by the coil and in turn this would have reduced the sparking problem at the key contacts. The disc would have acted as a short-circuited turn around both poles of the magnet in which eddy currents would have circulated, giving rise to the effects mentioned. However it would also have slightly increased the release time of the magnet and consequently slightly decreased the repetition rate of the action. Encouraging eddy current formation remains a standard technique in relay technology today when it is desired to prolong the drop-out time by 20% or so, and Hope-Jones would probably have been familiar with it from his time as a telephone engineer. In his patents he also mentioned the use of multiple windings connected in parallel, which would have enabled the current to decay more gradually when the key circuit was broken and thus reduce sparking. Whether he actually used this technique is unclear, though it would help to explain why his magnets were of such low resistance.

Thus Hope-Jones claimed that his magnet design had “eliminated” the sparking problem (mentioned in [34] and [36]), but he also maintained that his actions would repeat at 60 times per second [34]. The latter would have been most unlikely if only because of the magnetic inertia introduced by the zinc disc, thus even he could not have had it both ways! I have carried out a detailed study of the repetition times of electric actions which are reported elsewhere for those interested in a more comprehensive analysis of the issues involved in spark suppression and repetition rate [35].

Discussion of Hope-Jones's keying circuits will be deferred until his couplers have been discussed, as the two functions are inextricably interlinked at an electrical level.

Coupler Actions

Electropneumatic coupler relay

By the time he had set up his first company in the early 1890's Hope-Jones had introduced a novel type of electropneumatic relay switch for implementing couplers, and he used them in most of his subsequent organs in Britain. However, although I have no definite proof, he almost certainly did not use them in the slightly earlier organ at St John's, Birkenhead. Coupling there was probably done in a different manner and the reasons for this will be described presently. Aside from this and maybe a few other exceptions, he also saw that his switch could be used for implementing functions such as borrowing and extension, and ultimately this type of relay in a modified form became the prime technical enabler of the fully unified Wurlitzer theatre organ. Clearly based on those used in telephone exchanges where complex relays and circuits for functions such as automatic dialling were already being developed, it was the precursor of the ladder switch which was used widely in organs until the 1960's when electronic control gradually began to appear in the form of diode and transistor keying. Even so, electromechanical ladder switches are still obtainable today from organ supply houses.

Figure 12. A Hope-Jones coupler relay cabinet
(Copyright © Lancastrian Theatre Organ Trust)

Hope-Jones's coupler relay was mentioned earlier to illustrate some of the contact design techniques he used and its essentials were sketched in Figure 2. An actual relay cabinet containing many such relays is shown in Figure 12. In this example some of them controlled functions other than coupling, such as double touch and opening all the swell shutters simultaneously in response to his "swell shutters" stop tablet, and this illustrates the versatility of the scheme. The picture shows some of the electropneumatic relays of the four manual Hope-Jones organ of 1894 at St Paul's, Burton on Trent, now preserved in the Hope-Jones museum of the Lancastrian Theatre Organ Trust in Manchester. This organ was among the first built entirely by the fledgling Hope-Jones Electric Organ Company Ltd, and it appeared only a few years after his famous prototype at St John's, Birkenhead referred to above.

Behind the glass doors are vertical dowels containing metal contact pins. These were rotated by means of cranks attached to the pneumatic motors below, thereby bridging corresponding pairs of contacts which were wired from the rear of the assembly. The pneumatic tubing which actuated the motors can be seen, connected to primary electromagnets of the usual Hope-Jones pattern which were controlled by the stop tablets. The mechanism was double-acting, with a second row of motors at the rear to return the dowels to their original positions. Thus each electropneumatic relay required two magnets, one to turn it on and the other to turn it off. However, once the relay had reached its operating position the power was cut off automatically by means of two pairs of contacts at the bottom end of each dowel. These were wired as changeover switches (single pole double throw) and they were shown earlier in Figure 5. This is similar to the power saving scheme employed in the speaking stop slider mechanisms (described later) where the power was automatically shut off in the same way. It is worth remarking that the workmanship in this relay assembly was of the highest order, and it continued working until the organ was dismantled in the 1980's.

Circuits

We can do no better than examine one of Hope-Jones's own circuit diagrams for his key and coupler actions, and Figure 13 shows that which appeared in his patent 15461 of 1890. It is drawn in an obscure manner and its features could easily have been better presented by a more logical layout, but one reason for reproducing it here is to point out this unfortunate fact. This might have been yet another example of deliberate obfuscation on Hope-Jones's part because the circuit also contains a minor error, also perhaps deliberate, which is not obvious to the uninitiated. Like so much else of what he said and wrote, this should come as no surprise and I will discuss it presently. However none of this prevents us extracting the necessary information today, though at the time it would doubtless have aggravated the headaches of his competitors.

The circuit relates to the keying and coupling circuits for a two manual and pedal organ having four couplers – swell super octave, swell to great, swell to pedal and great to pedal. The corresponding coupler relays are denoted by the symbols I, II, III and IV respectively. The first 14 contact-pairs of each relay run horizontally across the diagram, from the bottom note C of each keyboard to the C# in the octave above. To prevent confusion, note the physical difference between this representation and the picture of some actual relays in Figure 12 where the contacts are stacked vertically. The afferent (input) connections to each relay contact are represented by the solid circles, and the efferent (output) connections by the open ones.

The key contacts of the manuals and pedals are shown placed under the keys and they are plainly of the multiple-wire and wiper type, with two contacts per key for the swell and great and three for the pedals. The supply voltage is connected directly to the wiper, not via an additional wire or wires in the contact block. As no additional key springs are shown it is possible that the wiper therefore performed the dual function of the spring in the actual organs.

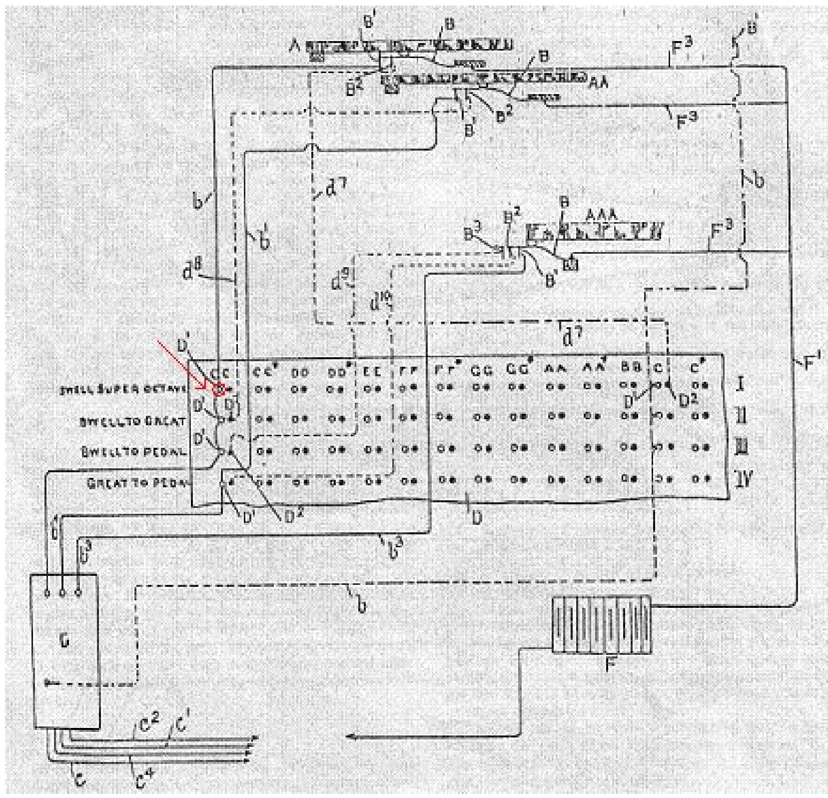


Figure 13. A Hope-Jones key and coupler action circuit with an error highlighted in red

For the bottom note of each keyboard a functional distinction is made in the diagram between the circuit for the note corresponding to its own department (solid lines) and the notes which can optionally be coupled to it (dotted lines). Confusingly, this convention is then reversed for the line marked *b* for the octave above which, because of its connection to the efferent contacts of relays I, II and III, would also have been connected directly to the tenor C key contact on the swell keyboard.

The rectangle *G* was referred to as the "test board" by Hope-Jones. It brings together the connections to every pallet magnet on the organ before they are routed to the various soundboards.

The battery is indicated by *F* and it appears to comprise 8 cells. If we take this at face value and if these were accumulator cells then the battery would have given 16 volts, but if they were dry cells the voltage would have been about 12 volts. Both figures are much higher than the 6 volts or so which Hope-Jones used in later organs, so whether this means the Birkenhead organ, which was contemporaneous with this patent, might have operated on a higher voltage is an open and valid question.

The error in the circuit mentioned above is highlighted by the red arrow pointing to the red circle in Figure 13. There cannot be any connections to the first 12 notes of the swell super octave coupler relay because these connections do not begin until tenor C, correctly shown by the dotted connection d^7. In fact this relay need not have incorporated any contacts at all for the first 12 notes and it is therefore confusing to have them in the diagram. Indeed, inspection shows that some of the actual relays in Figure 12 do not have a full complement of contacts, as would be expected. Therefore the connection highlighted here is redundant and performs no function. It confirms my view that, in addition to the web of confusion surrounding other aspects of this patent, it might have been part of a deliberate attempt to mislead all but the most educated and determined readers. In this Hope-Jones was far from alone in the patent literature either then or since.

The absence of through-coupling

A characteristic feature of this circuit is that the swell super octave coupler does not couple through the other couplers. That is, if all four couplers were drawn, the super octave notes on the swell would not sound when playing on the great and pedals. It affects notes played on the swell organ alone, and the other three couplers are therefore unison couplers only. Nor could the swell organ be played from the pedals when the great to pedal and swell to great couplers were drawn together – this would only happen when the swell to pedal was drawn also. This behaviour, the absence of through-coupling, was different to that of the mechanical couplers used in tracker action organs and many pneumatic ones, and it may have surprised organists at the time. However Hope-Jones always provided separate octave couplers to the other departments in his organs, thus in the case of this instrument there would also have been a swell super octave to great coupler and probably one to the pedals as well, even though they were not shown in Figure 13.

With the passage of time this difference in the behaviour of couplers between electric and mechanical action organs has become accepted as the norm by organists, none of whom appear to find it in the least remarkable. Even with today's diode keying and solid state transmission techniques the convention remains largely intact, though it need not because most electronic transmission system manufacturers allow customers to specify whether they want through-coupling or not. It would also have been feasible for Hope-Jones to have incorporated through-coupling in his organs, though it would have required some additional circuit complication. Thus the interesting historical aspect is twofold: firstly, Hope-Jones's keying and coupling circuits as described here were used without modification in most electric action organs until the 1960's when diode and transistor keying started to appear. Until then Hope-Jones's introduction around 1890 of multiple-wire key contacts and ladder-type coupler switches, together with the way they were interconnected, almost instantly became part and parcel of organ building practice worldwide. Secondly, the constraint this applied to coupling, in that sub and super octave intermanual couplers were sprinkled liberally across the stop lists of nigh on all electric action organs, is also a direct result of the influence of Hope-Jones which continues to this day.

Coupling in the organ at St John's, Birkenhead

The necessity for multiple-wire key contacts brought with it some practical problems. Logic dictates that the number of afferent wires leaving each contact block must equal the number of afferent couplers plus one. For example, in Figure 13 the pedal contacts have three wires – one for the pedal chest and one each for the two afferent couplers (swell to pedal and great to pedal). In an organ with many couplers, and therefore in almost all of Hope-Jones's organs, this meant that each key controlled many circuits. The stop list of the organ at St John's, Birkenhead with its 18 couplers (Appendix 1) means that it would have required key contacts with at least 6 wires for most of the pedal organ, 7 wires for most of the great, 3 wires for most of the swell and 6 wires for most of the choir.

Yet this organ was played from a mobile detached console on the end of a long cable which contained only 343 cores if the contemporary literature is to be believed [21]. There can be no doubting the mobility of the console and the length of the cable because of the surviving photograph which shows Hope-Jones playing the organ outside the church. The figure of 343 cores is also plausible, because if it was significantly greater then it would have been next to impossible for the resulting clinically obese cable to have had the required flexibility. So we are presented with a conundrum, because it would have been out of the question to accommodate all the keying and coupling circuits emanating directly from the key contacts within a 343-core cable. There would not have been nearly enough wires because well over 1000 would have been necessary for the entire instrument.

The most likely implication is that Hope-Jones would have put the coupler relays inside the console rather than at the organ end of the cable. The interconnections between the key contacts and the relays would then have been made at the console, resulting in only a single wire to each chest magnet running within the cable. With this assumption a plausible interconnection budget for the Birkenhead organ is derived in Appendix 1, which confirms that the figure of 343 cores is indeed reasonable. Electropneumatic relays of the type depicted above could not have been used because no wind could have been provided to the mobile and distant console, thus the type of relay employed must have been different to those used in later organs. Various options are discussed in more detail in Appendix 1, and the most likely one is that a compact combined key and coupler contact assembly was used, situated at the rear of each keyboard.

Speaking Stop Actions

At the start of his organ building career Hope-Jones used conventional bar and slider chests. The organ at St John's, Birkenhead was so constructed, no doubt because it was a rebuild of an earlier mechanical action instrument to which he applied his new electric action. However, even when building entirely new organs he still continued to rely on this venerable technology and he was still using it when he suddenly vanished from the British organ building scene.

Yet Hope-Jones had finalised his paper design of the totally unified organ at an early stage, with all pipes on sliderless unit chests controlled by his electropneumatic ladder relays. We can be sure of this because he introduced this new concept to the audience of his 1891 lecture to the College of Organists [7], only a matter of months after he had completed the Birkenhead organ and some years before he set up his first company. It is therefore legitimate to enquire why he did not move more rapidly towards the goal of unification, which continued to evolve relatively slowly during his time in the USA to finally emerge as the Wurlitzer theatre organ.

The fact is that there were at least two good technical reasons preventing him making more rapid progress. Firstly, a unified organ requires huge numbers of individual actions. Each pipe needs its own. This is quite unlike the more economical though less flexible slider chest, where only 61 or so key actions are required for as many five-octave stops as can reasonably be planted on it. In the early 1890's Hope-Jones could not possibly have set up the necessary mass production facilities in short order from scratch to produce untold thousands of virtually untried electropneumatic action units, despite the impressive financial backing he enjoyed from people such as Thomas Threlfall. The technical and commercial startup risks of such a novel and untested system would probably have been too great for the most intrepid venture capitalist to accept. Secondly, action power supply limitations were, quite simply, a potential show stopper at that time. We have already seen that Hope-Jones was power-limited as it was even for some of his slider chest actions because of the limited availability of mains electricity, town gas or high pressure water for blowing the organ and hence for driving a dynamo. Thus his smaller organs across large swathes of the country were necessarily blown by muscle power and they relied on batteries (usually accumulators) to power their actions. Undesirable at best, this would have been impossible if the instruments were fully unified with their many more magnets demanding much more power. In short, unification was an impractical system still somewhat in advance of its time in the 1890's.

As well as heeding these technical limitations it is likely that Hope-Jones had to proceed cautiously so that potential customers were not put off by too much novelty too quickly. In this he was no doubt counselled, indeed perhaps instructed, by the redoubtable Threlfall who became the chairman and major stockholder of his first company. His success in business probably meant that he had a much better understanding of the subtle balance to be struck between "supplier push" on the one hand and "customer pull" on the other, something which the naive and impulsive Robert might well have dismissed if he thought about it at all. The combined pressure of these technical and commercial constraints was that extension, borrowing and duplication emerged only slowly in Hope-Jones's organs in Britain, despite what his personal preference for more rapid progress might have been. There was little or none of it at St John's, Birkenhead in 1889. In the large four manual instrument at St Paul's, Burton upon Trent built by his first company in 1894, only the Bass Flute on the pedals was derived by upward extension from a 16 foot stop. The resulting 42 note sliderless rank was also made available on the great organ as a 16 foot flute in many later instruments though not, surprisingly, at St Paul's itself. Yet even when this was done the top 19 notes of the great organ stop were sometimes put on a slider chest, presumably to economise on magnets and actions (as in the extant organ at Pilton [26]).

Nevertheless, by the late 1890's Hope-Jones was becoming more adventurous and the large organ at St Modwen's (also at Burton) had extra bass and treble pipes for use with the sub and super octave couplers respectively. In addition this instrument had independent unit chests for an 84 note Tuba and a 73 note Diaphonic Horn. At Battersea Town Hall the excursions into similar territory were bolder still, though one should be cautious about regarding these organs as entirely Hope-Jones's own work because both were actually built by Norman and Beard. Even the Battersea organ still retained many stops on slider chests however.

For the purposes of this article the foregoing means that we have to review the means Hope-Jones used to control the sliders in his organs when we consider the speaking stop actions he used during his sojourn in Britain. His unit chests were controlled by relays of the type used for coupling, and we have covered these already.

Double-acting sliders and the Stop Switch

From the outset, and thus at St John's, Birkenhead, Hope-Jones used double-acting slider actions – when the stop was put on the slider was moved one way by an electropneumatic action, and when it was put off the slider was moved back using an independent second action. We can be reasonably certain of this on two counts – firstly there is mention in the patent literature c.1890 of the stop tablets operating two-way switches which were wired to the corresponding magnets in the two actions. Secondly there is incontrovertible evidence of the widespread use of double-acting slider machines in Hope-Jones's subsequent organs.

However, in its simplest form this arrangement had the disadvantage that each speaking stop consumed current as long as the organ was switched on, regardless of whether it was being played or not and regardless of whether the stops were on or off. For organs whose actions were powered by dynamos this did not matter very much because each magnet consumed only a small amount of current, typically 120 mA for a 50 ohm magnet working on 6 volts. Thus the 34 speaking stops of the Birkenhead organ would have drawn a standing current from the dynamo of just over 4 ampères, assuming each stop had a slider action. If the power had been supplied by accumulators the current drain of itself would not have posed a problem because accumulators can provide very large currents, but the life of the battery would have been curtailed before recharging was necessary. However if a dry battery had been used it would have become rapidly unusable because of short term fatigue due to hydrogen production. As well as the standing power drain the magnet overheating problem would also have been a consideration as discussed in a previous section.

Therefore one needs to ask why Hope-Jones used this system when he could have used a single-acting mechanism which worked against a return spring. In this case the stops would only have drawn current when they were on, a more economical arrangement. There were probably two reasons. One was that automatic power shutoff is possible, in theory, for double-acting actions because once the slider has moved to its correct position it no longer requires any force to keep it there. Another was that he wanted to introduce to the organ world his Stop Switch as a registration aid, and double-acting sliders allow the Stop Switch circuit to be particularly simple. The Stop Switch was a bistable push button (push on/push off) or stop tablet situated in the centre of the sweep of stops on nearly all his organs, usually duplicated by a pedal, and it was widely discussed in the musical literature of the day. It interrupted the current to all the speaking stops when it was opened so that their sliders would remain in the position they happened to be in. The organist could meanwhile adjust the registration, maybe while continuing to play, but the new setting would not take effect until the Stop Switch was closed again. Some literature from that era suggests that the first two registrations would be set up before commencing to play. The simplest form of circuit of this arrangement for five stops, each with a double-acting slider action, is shown in Figure 14.

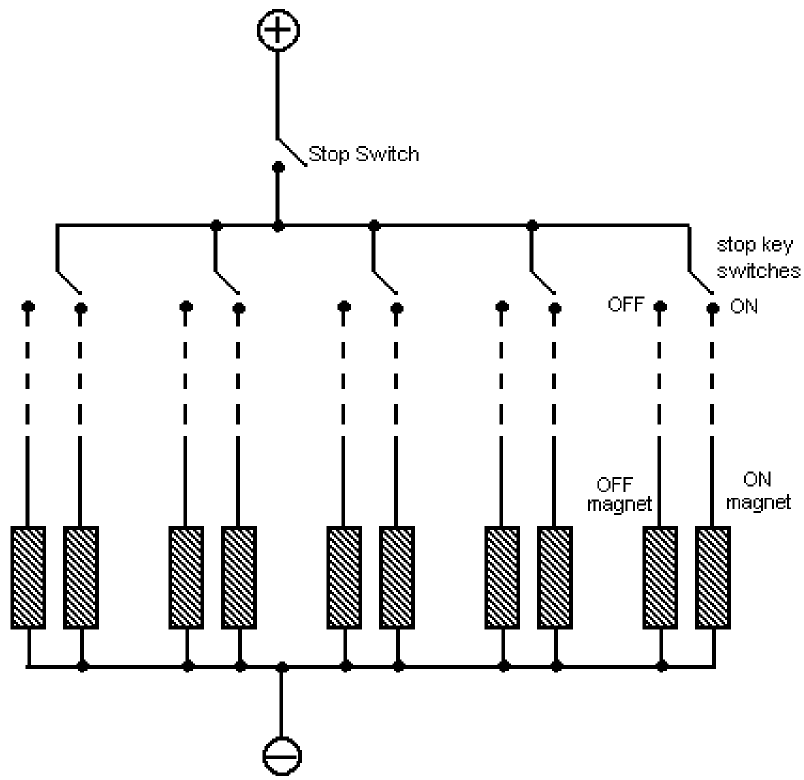


Figure 14. Simple Stop Switch circuit

At first sight it might sound an ingenious and useful scheme, but it is the sort of thing one needs to try before forming an opinion. Because almost no organist today has had the opportunity to do so it means their opinions are of necessity theoretical, so recently I decided to implement the Stop Switch when simulating the Hope-Jones organ at Pilton digitally [30]. For what it is worth I found it a confusing contrivance, just as with any other blind combination aid. One frequently forgets whether it is on or off, and then it is inconvenient (infuriating is a better word) to get caught out while altering the stops only to find that nothing happens. At that point you have lost the setting captured by the Stop Switch, and as likely as not you have little recollection of the other one. It is likely some organists of the day formed a similar judgement because the surviving organ at Pilton no longer has its Stop Switch, and it was likewise removed from others with the passage of time. The Worcester cathedral instrument was an exception however because Harrison and Harrison retained its Stop Switch when it was rebuilt in the 1920's.

It is also worth examining some other implications of the Stop Switch before moving on. Because it cuts off the current to all the speaking stop actions when the switch is opened some authors [31] have concluded that power saving was its intended function, its usefulness as a registration aid being a secondary spin-off. This seems rather far fetched, because it implies the organist would routinely close the Stop Switch prior to setting a new registration and then open it again afterwards. I doubt organists would have had the time to bother while busied with playing, and most would not have had the inclination! The fact is that the Stop Switch was also included in organs which incorporated means for shutting off the current to the slider actions automatically as we shall see. In these instruments the need for manual intervention to save power was irrelevant, indicating that it was indeed intended primarily as a registration aid, and we shall now look at actions of this type.

Automatic power shutoff

A modified version of the simple Stop Switch circuit which incorporates means to automatically shut off the power once the slider has moved to its new position is shown in Figure 15.

Each slider now operates an automatic changeover switch. Initially, imagine the Stop Switch to be closed, the stop key switch to be in the ON position as shown, and the changeover switch to be in the position shown by the full line. Thus no current will flow in that stop circuit. Now let the stop key switch move to the OFF position. Current will flow through the OFF magnet and therefore the slider will move such that the stop goes off, but at some point it will operate the changeover switch so that it assumes the position shown by the dotted line. At this point current flow will cease, leaving the stop off. When the stop key goes ON again the cycle repeats but in the reverse direction.

An embodiment of this system existed in the Battersea Town Hall organ at the time of its restoration prior to the fire of 2015, and one of the slider changeover switches is shown in Figure 16. Note the use of Hope-Jones's wire loop contacts to improve reliability as described previously in the section dealing with contact redundancy. The assembly is enclosed in a removable wooden hood to keep dust and dirt away. The contacts must have required careful setting-up and no doubt regular maintenance if the system was to work reliably over long periods.

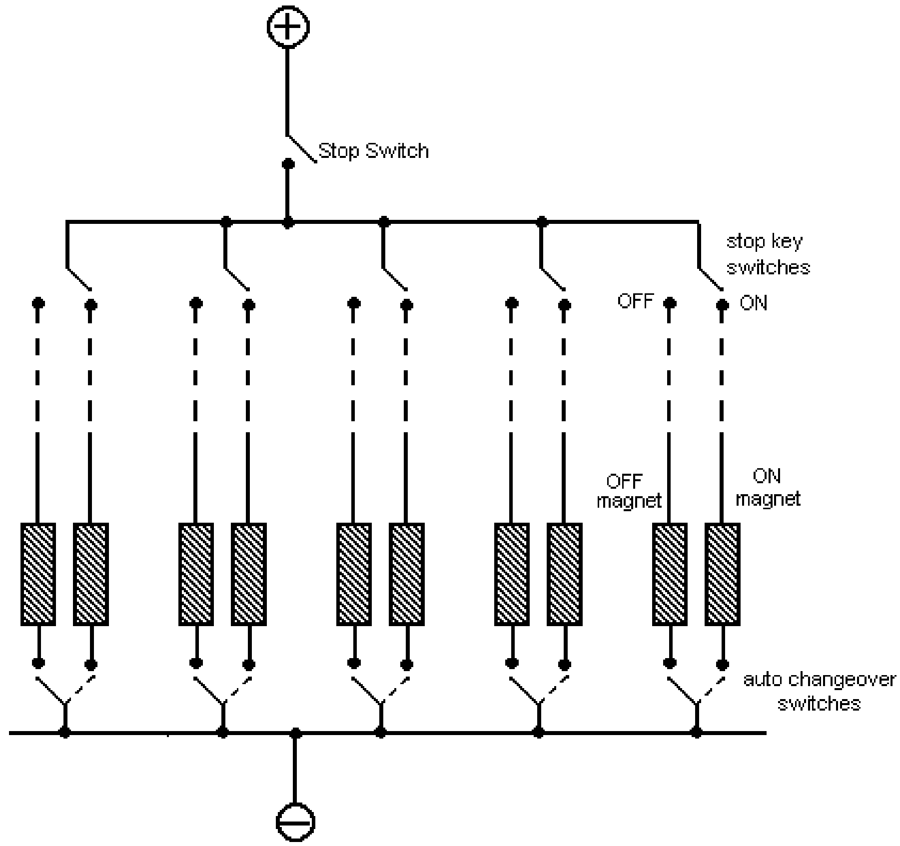


Figure 15. Stop Switch circuit with automatic power shutoff

Figure 16. Automatic slider changeover switch (Battersea Town Hall)

A view of some of the action magnets and primary pneumatics of the swell organ slider action at Battersea is shown in Figure 17, confirming that the action was indeed a double-acting one.

I have no knowledge whether Hope-Jones applied this system to his first organ at St John’s, Birkenhead. From the power saving point of view he would not have needed to because the organ action was powered by a dynamo. However this organ was the prototype test bed in which he used large numbers of magnets for the first time. Therefore if the power saving system was not used it is possible he first became aware of the need to shut off the power to his magnets merely to keep them from getting too warm, with adverse consequences for their insulation as discussed earlier. He might therefore have retrofitted the power saving system later at Birkenhead.

Figure 17. Double-acting slider machines at Battersea Town Hall
(Copyright © Lucien Nunes)

Combination Actions

The details of Hope-Jones's actions used in his consoles to bring on preset stop combinations are probably the most obscure aspects of his technical legacy, and hardly any two surviving consoles are alike in these respects. He described in his patents a large number of techniques to actuate the stop mechanisms when the combination pistons were used, and these can be classified under four headings: mechanical, electric, pneumatic and electropneumatic techniques. However one must be cautious about assuming that he actually employed any or all of them in his organs in the various forms described in his patent specifications, because what is said in a patent is one thing but what an inventor actually uses is often quite another. At the most fundamental level it is by no means always clear whether he used motorised (self-indicating) stop tablets or stop keys in any given instrument, or whether it had blind combinations which did not move the stop controls themselves. He mentioned both options in his patents, while expressing a preference several times for motorised actions.

On balance it is indeed likely Hope-Jones preferred motorised stop controls because of the range of different mechanisms he described to achieve this aim. His organs with consoles which were fixed in position could have used any of the four techniques mentioned above. However his mobile detached consoles on the end of a long cable, such as those at St John's, Birkenhead and the McEwan Hall in Edinburgh, could not have used an electropneumatic mechanism because of the impossibility of supplying wind to them and therefore their combination actions would have been restricted to using only three of the four options (including the fully pneumatic system described presently - this required no external wind supply as it used a self-contained bellows system). At the McEwan Hall the stop tablets were indeed motorised if the contemporary literature is to be believed (for example, a description of the McEwan Hall organ included the words *"all these combination movements affect the stop-keys themselves, so that the memory of the organist is not taxed"* [33]). It is not entirely clear whether this applied to the earlier Birkenhead organ however and therefore we have to proceed using collateral information and inference. There is no doubt that a comprehensive combination system was employed there from the outset because the earliest accounts of this organ describe in detail the combinations set on each piston or composition pedal [21]. It is also likely that the combination action was motorised if only because separate "suitable bass" (q.v.) and "independent pedals" options were also incorporated for each manual [21], and at least one of the associated thumb pistons can just be discerned in the photograph of Hope-Jones playing this organ outside the church (reproduced in Appendix 1). If blind combinations had been used, opportunities for the player to become hopelessly confused would have been legion with such a flexible system offering so many options. Therefore the following discussion assumes that motorised combination actions were used routinely. We do not lose generality in adopting this assumption, because modifying any of the mechanisms to operate a simpler blind combination system is straightforward should one wish to do so as an exercise, though some functionality might be lost in certain cases.

Mechanical combination actions

In patent number 15461 (1890) there is a description of a purely mechanical combination action. It knocked the stop keys (not tablets) on or off by means of a rotating roller situated behind the music desk. The stop keys consisted of two parts, one white and the other black and similar in appearance to the playing keys, though how often Hope-Jones might have actually used this type of stop control is unknown. By adjusting a pair of on/off pins in this roller for each stop, barrel-organ fashion, the desired combination could be set up. The roller was rotated by means of a chain driven by a combination tab situated below the sweep of stop keys, and the system is illustrated in Figure 18.

Instead of the chain drive, a mechanical linkage between a foot-operated composition pedal and the roller would have been feasible in some consoles, though at St John's with its "skeleton" console it is difficult to see how this could have been done without the mechanism being visible in the extant photograph. Bowden cables as first used on Raleigh bicycles could not have been used because they were not invented until several years later. Nor is it easy to see how the rollers could have been operated mechanically by thumb pistons or compound composition keys (q.v.), or how they could have been integrated within the electrical system of "suitable bass" (q.v.) and "independent pedals" used at Birkenhead. However we probably need surmise no further because the extant photograph of the Birkenhead console shows no sign of the combination tabs situated between the stop keys and the swell keyboard. It is therefore reasonable to assume that a mechanical combination system was not used on this organ, though whether Hope-Jones used it elsewhere is not known.

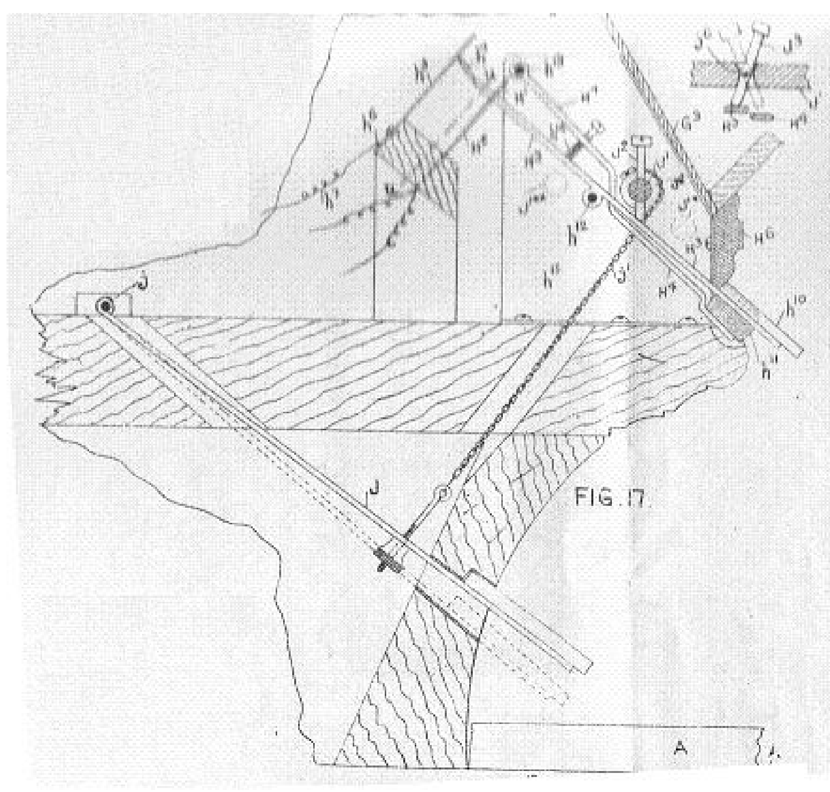


Figure 18. Mechanical combination action

Electric (electromagnetic or direct electric) combination actions
There is no doubt that Hope-Jones considered applying purely electric (electromagnetic or direct electric) actions to all of his mechanisms, not just his combination actions, because almost every conceivable application is described and illustrated in his patents. Therefore, because his thinking obviously proceeded along these lines, it is worth expanding the discussion somewhat.

In his patent number 28157 of 1897 is an interesting diagram which is reproduced here at Figure 19.

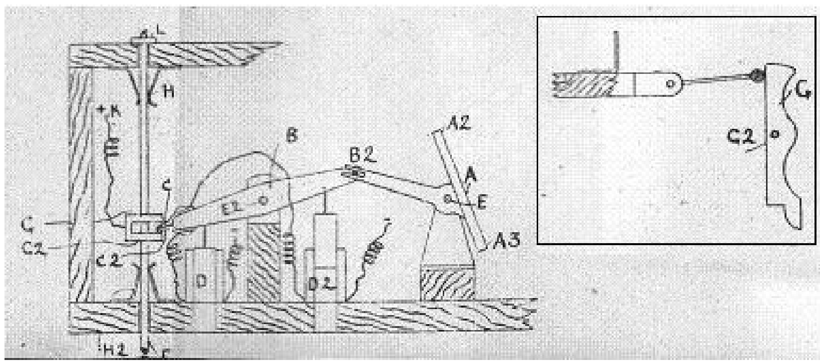


Figure 19. Solenoid-operated actuating mechanism

At first glance it looks exactly like the type of mechanism one might have expected to find behind a motorised stop tablet of the sort used by Hope-Jones in his organ at St John's, Birkenhead, particularly as such a tablet was sketched separately on the same page of the patent (here this sketch has been inset into the box in Figure 19 for convenience). The components labelled *D* and *D2* are solenoids with plunger armatures, and the vertical rod operates electrical contacts. But closer reading of the patent reveals that the inclined plate *A* is in fact a swell shoe or pedal, not a stop tablet, and the intention was that the solenoids would assist the player's foot in moving it. However this seems an utterly implausible scheme for several reasons. Firstly, there would be no need for assistance when the connection to the swell shutters was not mechanical – the pedal on its own could have been moved easily without any form of assistance. Secondly, the solenoids would have had to be enormous if they were to contribute forces of a magnitude comparable with or greater than that which a player's foot could exert. Thirdly, and consequently, the amount of electrical power required would also have been enormous and one can legitimately query whence it would have been derived in Victorian organs. Fourthly, the appearance of such a power-hungry mechanism precisely at the time (the late 1890's) when Hope-Jones was busy trying to *reduce* the power consumption of his organs in every other regard seems absurd – we have already covered the power saving measures introduced into his stop slider actions for example. However the absurdity vanishes if we allow that plate *A* was in fact a stop tablet, not a swell pedal, because the amount of power required to move it, although still significant, then becomes much lower. In the patent Hope-Jones emphasised that all the descriptions were illustrative of generalised applications rather than particular ones.

Whatever the details of their mechanism might have been, some aspects of Hope-Jones's possible electromagnetic stop tablet actions can be inferred from basic engineering considerations. As with most of today's stop key units, the stop tablets on the console at St John's, Birkenhead had a mechanical toggle arrangement which gave them a positive tactile feel (though some modern ones use permanent magnets to produce the same effect). A contemporary first hand account referring to the Birkenhead organ [21] stated that *"these* [the stop tablets] *are placed immediately under the music desk, and consist of a row of ivory tablets (about the size and shape of dominoes), pivotted* [sic] *on a wire running through their centres and so arranged that the lightest touch upon the upper ends will cause the stops to speak, while a similar touch on their lower ends will silence them. A very simple and ingenious spring throws them fully on or fully off, so that they cannot rest in* [the] *middle position, and it becomes perfectly easy to see whether they are on or off"*. From this account we can also note that the on-off convention was different to today's custom, in which the stop is usually put off when the tablet is touched at the top and *vice versa*.

The mechanical characteristics of the toggle spring are important in this type of stop unit because they determine the force required, and hence the amount of electrical power required, to move the mechanism when the combination pistons are used. In today's electromagnetic stop key units the magnets require at least 12V, often more, and they consume at least 0.5A if the movement is to be reliable. This corresponds to a minimum electrical power demand of about 6W per magnet. Therefore it is not unreasonable to postulate that Hope-Jones's stop action magnets, if he used them, would have consumed at least 1A at his normal action voltage of approximately 6V. Although there is some room for leeway in these figures it is doubtful that reliable operation would have been achieved if they were significantly different. Electromagnetic stop key actions remain notoriously unreliable to this day if sufficient power is not available to apply enough force to the mechanism.

Taking the Birkenhead organ with its 53 stop tablets as an example, this means that a 6V power source capable of delivering at least 20A would have been required for the combination action alone. This is because the pistons were wired to give fixed (non-adjustable) combinations whose compositions we know [21], and some of them would have affected around 20 stops at once if the "suitable bass" (q.v.) option had been selected. As the organ action was powered by a dynamo this would not have presented a problem in principle, but it would have meant that heavy gauge conductors would have been required within the 45 metre multicore cable connecting the console to the organ so that the voltage drop would not have been excessive. Hope-Jones mentioned this requirement in his patents.

The requirement for a power source capable of delivering several tens of ampères means that all of Hope-Jones's organs with mobile consoles would either have had to be powered by dynamos, as was the case at St John's, Birkenhead, or by accumulators. Dry cells could not possibly have been used because they could not and cannot supply peak currents of this order. The mid-life internal resistance of a 6V dry battery (four cells in series) is typically about 0.5Ω, meaning that the maximum possible current is limited to about 12A, and at this value the terminal voltage will have dropped to zero so the battery could not drive a load. In other words this is the short-circuit current of such a battery. But currents of this order will rapidly render dry cells useless in a matter of minutes or even seconds owing to the short term fatigue problem due to hydrogen production. This casts doubt on the reliability of the reference already quoted concerning the McEwan Hall organ [33] which stated that motorised stop units were used, because elsewhere it said that *"this* [action] *current is supplied by a few dry cells"*. Either the stop tablets were not motorised, which seems unlikely given the inclusion of Hope-Jones's "compound composition keys" (q.v.) at the console, or they were operated by means other than a direct electric action, or the action was powered otherwise than by dry cells. The latter two options are the more credible alternatives, and alternative combination actions will be discussed presently. At this juncture it is worth noting that we have arrived at one of the conundrums which remain part and parcel of Hope-Jones's legacy today.

Continuing for the moment with electromagnetic stop actions, an interesting hybrid power supply option is worth discussing. If both a dynamo *and* accumulators were used then the power rating of the dynamo could have been much lower than that suggested above. It could have trickle-charged the accumulators continuously at a relatively low current (typically an ampère or so), with some additional capacity for supplying a few more ampères to the key and stop actions while the organ was being played. The occasional high but brief peak current demand of the combination action would then have been catered for by a burst of power from the accumulators, with the charge taken out of them being replenished more slowly via the trickle charging. The suggestion makes sense because it capitalises on the fact that the mean power requirement for any organ action is significantly lower than the peak power requirement. Thus a smaller dynamo delivering only 10A or less could have powered the Birkenhead organ using this system. Moreover, if the accumulators had been placed within the console an additional advantage would have been that the heavy gauge conductors required in the interconnecting cable between console and organ could have been reduced in size. Beyond occasional maintenance at tuning visits and infrequent replacement, the presence of the accumulators would have been transparent to the customer in an organ using this system because charging would have been taken care of automatically. Systems such as this would have been familiar to Hope-Jones because they were used in so-called CB (Central Battery) telephone exchanges from the outset, and they remained in use in the UK until the 1980's when relay switching was finally displaced by digital techniques. Therefore it would not have been in the least surprising to find he used the system in some of his organs, those with mobile consoles being the obvious candidates.

The conclusion is that there is no fundamental engineering reason why Hope-Jones could not have used electric stop tablet actions, especially as his thinking obviously followed along those lines. They would have been particularly suitable for his mobile consoles such as those at St John's, Birkenhead or the McEwan Hall. The nearest I have come to finding firm evidence that he actually went in this direction is from an interesting anecdote attributed to the American organ builder, Ernest M Skinner, concerning the Hope-Jones organ of 1895 at St George's, Hanover Square in London. Apparently Hope-Jones demonstrated it to Skinner in 1898, and the latter remarked on " *... the combination action which worked from the street current with such force that it could be heard all over the church. It was simply impossibly noisy ...* " [42]. A useful amount of information can be extracted from this remark. Firstly, because the mechanism was said to have operated from "the street current", it implies that the action was almost certainly electromagnetic (direct electric). Clearly, the amount of power applied to the stop tablet mechanisms was significant, and it appears that it was derived from the mains supply. However this probably does not mean that the mains voltage was used directly (!) even though there had been two previous fires, the combined result of which had damaged the organ to such an extent that it had been rebuilt by the time Skinner saw it. Had the fires been caused by the electric action itself it is unlikely that Hope-Jones would have been called upon to reconstruct the instrument. It is more likely that the combination system (and probably the entire organ action) was powered from the mains in one of two ways. If the local mains supply at that time was of direct current, a motor-generator set (sometimes called a dynamotor or rotary converter) must have been used to reduce the voltage to a manageable and safe value. At that time there was no other option for DC to DC conversion, indeed the technique was used to power telephone exchanges [43] and Hope-Jones would have been familiar with it. If alternating current was available a motor-generator could still have been used because it would, conveniently, have provided an output at DC. However a transformer could also have been employed in this case, but this would have meant that the organ action would have worked on AC because there was no means of converting (rectifying) AC to DC at that time other than by using the rotary conversion technique. AC operation is a distinct possibility given Skinner's emphasis on the noisiness of the action, because electromagnets operated on AC tend to buzz or chatter quite noticeably. (As an aside, it would also have prevented residual magnetism developing in the magnet yokes of the key action).

A second conclusion which can be extracted from Skinner's anecdote is that the combination action obviously must have been motorised. A blind combination system would have made little or no noise. Noisy electromagnetic combination actions for operating stop keys were by no means limited to Hope-Jones's organs, because they persisted well into the twentieth century in those of some other builders. Compton's stop key units were notoriously noisy, though the clatter they made when the pistons were used was simply because felt buffers of inadequate thickness were employed in the mechanisms. Because Compton copied so much else of Hope-Jones's thinking, might it be possible that his motorised stop key mechanisms were similarly plagiarised? Likewise, Willis III's tilting tablets were noisy in his all-electric consoles.

Finally, one must counsel caution when taking any of Skinner's opinions concerning Hope-Jones at face value because he adopted strongly polarised views which differed at different times. On the one hand we have his iconoclastic observation quoted above, yet Hope-Jones was nevertheless taken on in a senior capacity by Skinner only a few years later when H-J had emigrated to America, and we have a eulogy attributed to Skinner containing remarks testifying to the value both of Hope-Jones's mechanisms and of his tonal innovations [44]. It is possible that Skinner moderated his public writings and utterances once he became aware of the esteem in which Hope-Jones was held in America because it could have adversely affected his own business, only allowing himself more freedom of expression well after Hope-Jones was out of the way. The situation becomes even more confused when we look at Skinner's own approach to combination actions. On the one hand, Barnes tells us that Skinner "entertained strong opinions" on the matter of whether combination actions should be blind or motorised [45], though without actually saying which he preferred.

On the other, strong opinions or no, Skinner himself completely ignored the subject in his own book on organ building [46], even in the section dealing with console design.

Nevertheless, there is clear evidence that Hope-Jones used an electromagnetic motorised combination action in his organ at St George's, Hanover Square. Therefore there is no reason why he could not have done so in others, provided the necessary prime power was available as discussed already.

Pneumatic combination actions

A purely pneumatic stop tablet combination action was described in Hope-Jones's patent 18073 of 1891. Illustrated in Figure 20, it consists of a bellows connected to a foot-operated composition pedal. The air from this moves the stop tablet on or off according to how the fans F^2, operated by the actuating motors F^6, had been set beforehand when setting up the desired combination. (The pedal also illuminates a small lamp below the stop rail, a clear indication of the inventor's pedigree in telephone engineering!). Although this is a pneumatic action, it is noteworthy that it requires no air supply to the console and therefore it would have been equally applicable to both attached and (distant and mobile) detached consoles.

As with the mechanical system described already, it is difficult to see how the cumbersome bellows mechanism could have been operated by thumb pistons or compound composition keys (q.v.), or how they could have been integrated within the electrical system of "suitable bass" (q.v.) and "independent pedals" used at St John's, Birkenhead and elsewhere. Therefore its use in this organ seems somehow unlikely.

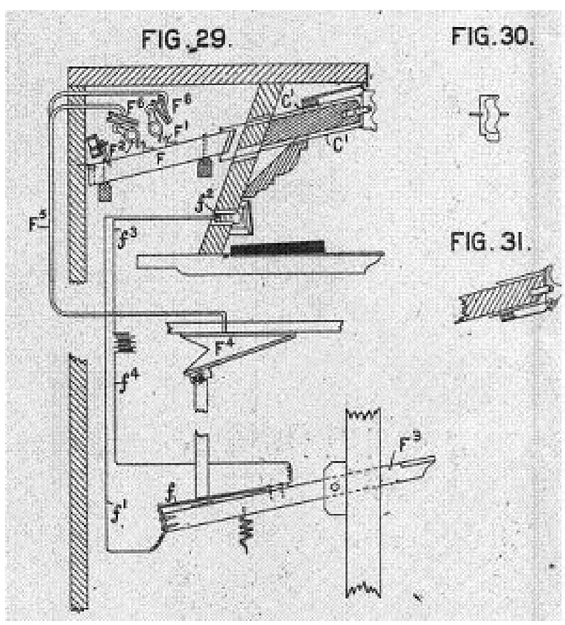


Figure 20. Pneumatic stop tablet combination action

Electropneumatic combination actions

The use of an electropneumatic combination action has the advantage that the high peak current demand of an electromagnetic one is reduced by a large factor, typically ten or so. This would have made them attractive in situations where battery power had to be used. However the not insignificant downside was the considerable additional complication of the action and fitting it into the necessarily confined space behind each stop key.

Hope-Jones invented several types of electropneumatic combination action and he used them widely, though it is important to bear in mind that this form of action could not have been used in his detached consoles on the end of a long cable because the necessary wind could not have been supplied to them. One of the simplest types was also one of the earliest, and it was incorporated in his organ of 1894 at St Paul's, Burton upon Trent. This instrument used tilting tablets similar to those on the prototype organ at St John's, Birkenhead and on some later ones such as that at Worcester cathedral. A photograph of the rather impressive console, now in the Hope-Jones museum of the Lancastrian Theatre Organ Trust in Manchester, is at Figure 21.

Figure 21. St Paul's, Burton upon Trent, 1894

In some respects the mechanism (Figure 22) is an elaboration of the purely pneumatic one shown in Figure 20. The stop tablets operate a wooden trace or drawbar which has small brass angle brackets or fans on its upper and lower surfaces – these are placed by the user in the appropriate positions for the combination of stops desired. Those on the upper surface turn the stop on, and those on the lower turn it off. There are separate fan positions on each trace for each piston on that department, and they are actuated by brass rocking bars which run across all the traces – those on the top surface are clearly visible in Figure 22, and there is a corresponding set underneath which move in the opposite direction.

Each dual rocking bar assembly, upper and lower, is connected to one of the pneumatic power motors visible in the photograph. These operate when the electromagnet of the corresponding piston is energised, which is contained in a separate magnet and valve chest and connected to the power motors via the tubing which can be seen. Thus when a piston is pressed, each stop moves in a direction depending on whether it has a fan for the corresponding rocking bar assembly on the upper or lower surface of its trace.

Figure 22. St Paul's, Burton – combination action
(Copyright © Lancastrian Theatre Organ Trust)

By about 1900 Hope-Jones and his licensees were using an early form of stop tab which superseded his previous tilting tablets. These looked similar to those we are familiar with today, though some writers at the time were taken aback by their similarity to a row of projecting teeth. They were operated by an elaborate, some might say excessively elaborate, electropneumatic mechanism and they can still be seen in a few surviving consoles, one being that at Battersea Town Hall and another at St Modwen's, Burton upon Trent which is in the Hope-Jones museum of the Lancastrian Theatre Organ Trust. The heart of the mechanism was an ingenious electropneumatic flip-flop (bistable) arrangement which predated by nearly 20 years the entirely electronic version invented by Eccles and Jordan which subsequently bore their names. A bistable system has two stable states in either of which it can remain indefinitely until it suddenly flips (or flops) into the other one by the action of a momentary external stimulus. Thus while Queen Victoria edged towards the close of her melancholy reign, her more dynamic subject was using binary logic devices which were identical in concept to those which underpin today's computer technology but which used an electropneumatic rather than an electronic basis of operation.

In point of fact the idea of bistable devices was not new because they had already been used in complex control systems such as telephone exchanges for some time, and in these applications they were implemented using a pair of ordinary relays. Hope-Jones would probably have known this, but the novel aspect of his electropneumatic version was that no electrical power was consumed in either of the stable states but only during the fleeting instant that it was changing from one to the other. Moreover, even when power was being consumed it was only that amount necessary to activate one of his ordinary chest magnets for each stop. Typically each magnet would have consumed 120 mA at 6V, leading to a transient peak power consumption of only 0.72W per stop. This was only about $1/8^{th}$ of the power consumed by the postulated electromagnetic system described above, hence its attractiveness for battery powered organs. From today's viewpoint it is also worth remarking that it is only because CMOS digital technology consumes no power while it is in one of it stable states that computer chips are enabled to have the necessary low power consumption and therefore to exist at all. Otherwise they would run at an incandescent temperature! This is another fascinating parallel with Hope-Jones's electropneumatic logic device.

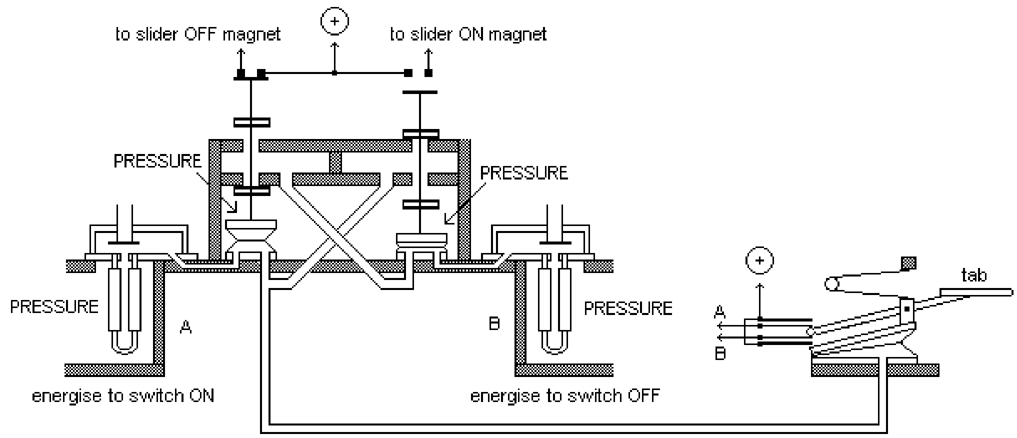


Figure 23. Electropneumatic combination action

The arrangement is sketched in Figure 23. This is not in any way a working drawing of an actual system because several details such as return springs and the precise implementation of the valves have been omitted or simplified in the interests of clarity. Nor is it drawn to scale as the intention is simply to illustrate generically how a rather complex piece of mechanism works. The stop tab is mounted at one end of an actuator bar whose other end floats freely between two pairs of sprung contacts, both of which are normally open. Therefore a very slight movement of the tab in response to finger pressure, either up or down, will momentarily close one or other of the contacts. The bar is pivoted in a trunnion along its length, the trunnion being mounted on the top board of a small hinged pneumatic motor. The flip-flop consists of two action magnets of the usual Hope-Jones pattern which each control a small pneumatic motor. These and their valves are cross-coupled as shown in the diagram, this dual positive feedback feature still characterising all bistable devices including today's electronic ones. Each of the motors operates an electrical contact which sends current to one or other of the double-acting stop slider actions (via the automatic power shutoff circuitry described previously).

In the diagram the stop is off (its uppermost position). If the tab now be depressed slightly by finger pressure, current will be sent to magnet A which causes its associated motor to collapse. As this happens the other motor will start to inflate because of the pneumatic cross-coupling, the motion of the two motors being in the form of a rapid snap action because of the positive feedback effect of the two coupling loops. Once motor B has inflated current will be sent to the ON magnet of the slider action, but because pressure has now been lost in A the stop tab motor will also collapse under the action of the spring shown in the diagram. Thus the tab will move downwards and remain in this position until lifted on its underside, when the cycle repeats but in the reverse direction.

Not shown in the diagram are the connections to the combination system itself. The piston contacts are connected directly or via a multipole relay to magnet A to switch the stop on, and to magnet B to switch it off. In either case the state of the flip-flop would change if necessary, and the stop tab would move as required.

The system requires nice attention to details such as the valve apertures, tube diameters and operating clearances before it will work properly, which is comparable to getting the resistor values correct in an electronic flip-flop. Also it is worth pointing out that the stop tab itself has no mechanical toggle action and therefore the tactile “feel” of the system is quite different to that we are used to with today’s stop keys. Once the contact has been made at the rear of the stop key, it jumps away from the finger in a slightly disconcerting fashion – the stops seem to have a life of their own until you get used to it. This type of pneumatic assistance was described in a general way in patent 28157 of 1897 though the details differed. Another curiosity is that the entire row of stop keys slowly rises when the wind is switched on and falls when it is switched off, although it does have the advantage that the stop keys are self-cancelling. This could have been important in the context of the ‘master reset’ system discussed in a later chapter.

Intriguingly elegant though it might be, the system seems unnecessarily complex and one wonders how reliable it would have been over long periods with all that exposed and fragile pneumatic leather work which is so attractive to vermin and prone to decay. It also has the look of a rather expensive system. It is interesting to speculate why Hope-Jones discarded the simple idea of the mechanical toggle spring action he had previously used in his stop tablet mechanisms, because this would have removed the need for the bistable pneumatic circuit to maintain the tab in the chosen position. By merely reinstating a toggle spring for the tab movement it is possible to simplify the system considerably while still retaining the advantage of zero power consumption in the stable states. Indeed, the later electropneumatic stop key actions of Wurlitzer theatre organs were of this simplified form.

A view of the electropneumatic combination mechanism behind the stop keys in the console of the organ at Battersea Town Hall is shown in Figure 24.

Figure 24. Electropneumatic combination action at Battersea Town Hall

A similar system was used in the slightly earlier organ of 1899 at St Modwen's, Burton upon Trent, though the implementation was somewhat less compact. Like the one at Battersea, this organ was in fact built by Norman and Beard. It is therefore possible that they were responsible for the apparently 'streamlined' version of the system at Battersea.

A photograph of the rear of the St Modwen's console is at Figure 25, and the row of action magnets can be seen at the bottom of the picture. These were controlled by the combination pistons and they operated the corresponding pairs of cross-coupled pneumatic motors above. These were linked mechanically by wires and buttons, the wires operating disc valves (which cannot be seen) on the underside of the chest at the top of the picture. The chest, which was charged with wind through the large black trunk on the left, contained the power motors for operating the stop keys attached to the backfalls above.

Figure 25. Electropneumatic combination action at St Modwen's, Burton upon Trent
(Copyright © Lancastrian Theatre Organ Trust)

Pistons, composition pedals, compound composition keys, etc
Hope-Jones used several types of console switches for operating his combination actions. Most of his organs had the same type of foot-operated composition pedal that he used in his first organ at St John's, Birkenhead, and these were of the projecting lever pattern which was usual at that time. Because most of his combinations were fixed (i.e. non-adjustable) the pedals were generally marked with dynamic indications ranging from *pp* to *ff*. These are still to be seen on his surviving consoles such as that at Pilton in Devon [26]. Other consoles used toe studs similar to those of today, though these might have been retrofitted at a rebuild.

He also introduced thumb pistons in the Birkenhead organ to implement functions called "suitable bass" (q.v.) and "independent pedals". Similar in concept to today's "manual pistons to pedal combinations" (though far more functionally elaborate in the most advanced embodiments), they either added a suitable combination of pedal stops and couplers to any manual combination, or they left the pedal stops independent. Mentioned and illustrated in British patent number 15461 of 1890, the pistons were mounted in the key slips in the usual manner and some can just be discerned in the photograph of the Birkenhead organ included at Appendix 1. Like so much else of what he did, this concept was carried almost unchanged into later theatre organ practice, and later patents described ever more complex elaborations of the system. Some of the circuits he developed to automatically add suitable pedal stops were pretty complicated, and even today it demands an expert with a clear head to fully understand some of the descriptions in his patents. It is worth noting that the system automatically moved the pedal stop and coupler tablets or keys as if by magic as the organist altered the manual combinations. Many organists of the day appeared to have an insatiable appetite for such novelties to judge by some of the contemporary literature (see, for example, [40]).

Figure 26. St Modwen's, Burton - compound composition keys
(Copyright © Lancastrian Theatre Organ Trust)

Hope-Jones also introduced several interesting variations on the theme of thumb pistons, the most complex and probably the least ergonomically attractive being his so-called "compound composition keys", though Bicknell said they were colloquially referred to as "liquorice allsorts" at the time [28]! Figure 26 shows some on the organ at St Modwen's, Burton upon Trent (e.g. note the one marked *f*), and they consisted of three independent parts. According to one of Hope-Jones's patents, the dark-coloured part on the left brought on stops for that manual only. Depressing that on the right would bring on suitable pedal stops plus couplers for that manual combination, and the white central button would activate both at once. This latter had no electrical contacts of its own; it merely pushed down both of the darker ones. However the contacts could obviously be wired as desired to suit a particular organ or its organist's wishes, so the description just given is illustrative only. Given the difficulties of operating ordinary pistons in the midst of a performance, the utility of compound composition keys somehow seems questionable. Nevertheless Hope-Jones and his licensees used them widely, and Harrison and Harrison apparently retained them in 1925 when rebuilding Hope-Jones's organ at Worcester cathedral [20].

Circuits

Circuit logic dictates that pistons of any type each require a dedicated multipole switch or relay, the number of contacts equalling the number of stops to be controlled. Hope-Jones used several methods to implement the switching. He may have used mechanical switching in some cases in which the piston operated the contacts directly. This method is economical and convenient if the space is available, as it usually is in the case of foot-operated composition pedals, because it does away with the need for a separate relay. A sketch from one of his patents is shown in Figure 27, which also shows how double touch was implemented. The multiple contacts controlled by the pedal can be seen, their different lengths depending on whether they were active on the first or second touch.

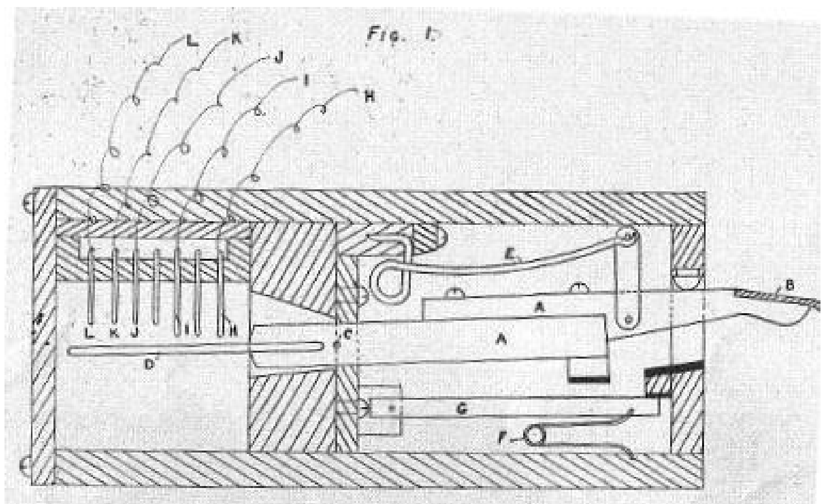


Figure 27. Double touch composition pedal arrangement

Hope-Jones may also have used direct mechanical switching of multiple circuits for thumb pistons if the number of circuits to be switched was not excessively large, and the method was also used for many years by other organ builders. For example, the all-electric consoles of Willis III designed by Aubrey Thompson-Allen in the 1930's were still using this technique which is illustrated in Figure 28. Note the use of several contacts for the common connection to supply the combined heavy current to the stop action magnets. This prevents overloading and rapid contact erosion.

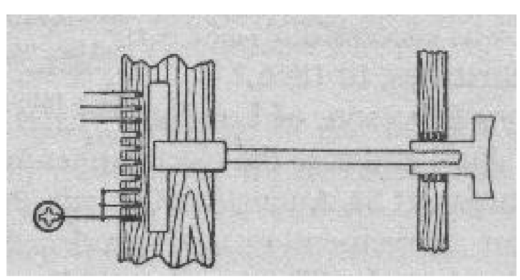


Figure 28. Mechanical switching of combination piston circuits (Willis III)

Otherwise Hope-Jones used electropneumatic or electromagnetic relays, the choice being partly dictated by the type of console because wind cannot usually be supplied to one which is mobile and remote. In these cases the piston only had to control a single contact which in turn operated a relay, and a sketch of such a mechanism (again from one of his patents and again for a double touch piston) is shown in Figure 29.

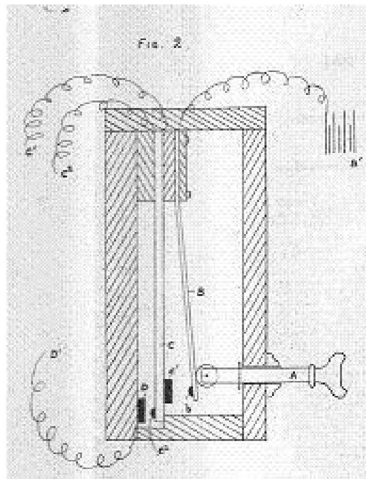


Figure 29. Double touch thumb piston arrangement

He seemed to move only slowly towards adjustable combinations. At St John's, Birkenhead there was quite an elaborate piston complement though none was said to be adjustable [21]. Eight years or so later, in 1897, he was still providing no more than one adjustable piston per department in the McEwan Hall organ (some departments had none at all) [33]. If using electrical control of the stops he would have had no alternative in his early organs than to use the humble setter board for the adjustable pistons, and although these are simple in concept they involve an enormous amount of additional wiring if all the pistons are to be adjustable. The number of setter switches involved is also large in these circumstances. Therefore it is possible he was limited by cost considerations as much as by anything else when deciding how many adjustable pistons to include in an instrument. However he might also have used the mechanical pinned roller system already described for his adjustable pistons. In later instruments in America he developed and used various capture systems of the type we still use today, in which the organist can quickly set the combinations on any piston while sitting at the console.

Suitable Bass

The system which Hope-Jones called "suitable bass" has been mentioned several times, and it now deserves a few paragraphs to itself. There is, however, a difficulty in that it actually embraced a *range* of techniques rather than just a single one, and it is therefore difficult to be certain which of these were actually embodied in which of his British organs (the subject of this article) as opposed to those used later in America. Nevertheless, there is no doubt that the system in one form or another surfaced in at least some of his organs on both sides of the Atlantic; his celebrated instrument at Ocean Grove NJ was one. The prime objective of all of the systems he described in his patents was to bring on a suitable selection of pedal stops for the manual combination currently in use. It is important to realise that today's "manual pistons to pedal combinations" draw stop or stop key is but a distant and rather pale reflection of the sophistication of the most elaborate mechanisms which Hope-Jones envisaged over a century ago. Yet, as this was one of the simpler systems he invented and employed (though sometimes under other names), we shall dispense with it first. For example, there is a rocking tablet labelled “Great Pistons to Pedal Pistons” in the bass cheek of the great organ keyboard still to be seen in the surviving console of the 1894 organ at St Paul’s, Burton upon Trent (Figure 21). However, given the distinctly ‘early twentieth century look’ of this console endowed by its probably non-original thumb pistons and toe studs, it is possible this was a later addition.

We have also seen that his three-way compound composition keys were in effect an embodiment of this straightforward idea – one merely pressed the appropriate part of the key if one wished to add a suitable selection of pedal stops to the manual combination currently in use, or one pressed another section to bring on both at once. Technically, the issues were trivial from an electrical point of view. Both the manual and the pedal combinations were set in advance using some form of hard-wired selector system, nothing more elaborate than a setter board, and they were activated or not depending which contacts were closed when the chosen part of the composition key was activated. Similar arguments apply to the double touch composition pedals and thumb pistons already described and illustrated in Figures 27 and 29 respectively.

The more interesting aspect is that, from the outset, Hope-Jones obviously had in mind a much more flexible and adaptive system (today we would call it “intelligent” or “smart”) which would automatically select pedal combinations appropriate to the manual combinations currently in use, and which would continuously optimise them as the player manipulated the stops. One can make this statement because his earliest patents described a system of “suitable bass” and “independent pedals” for each keyboard, and there can be little doubt that he implemented it in some form in his first organ at St John’s, Birkenhead. We can be reasonably sure of this because some of the thumb pistons denoted “S” (for suitable bass) and “I” (for independent pedals), as described and illustrated in his earliest patents, are those probably visible in the key slips of the Birkenhead organ in the extant photograph showing him playing it outside the church (see Appendix 1). Therefore, the only uncertainties centre around whether the system was complete at the time the instrument was first unveiled to the world, or whether it was completed later. Pope [41] implied the latter was the case, though on somewhat shaky grounds by merely parroting what another author (Whitworth) had written. Whichever was the case, it is rather irrelevant. Many organs today only have facilities which are “prepared for” at the time they are actually inaugurated.

In its most advanced form, according to his patents, Hope-Jones saw suitable bass as a system which would change the pedal stops automatically as mentioned earlier, thus they would physically re-arrange themselves as necessary (implying motorised stop tablets or stop keys). There is little doubt that he did eventually implement these systems, at least in America if not in Britain, if descriptions such as those of Miller [40] are to be taken at face value. The methodology outlined in his patents is of the utmost sophistication for its day, and the interested reader is recommended to peruse it there because the details are too involved to explain here. Basically, the idea was to assign a “weight” (not the term used by Hope-Jones but one which engineers would recognise today) to each manual speaking stop based on its loudness. Each weight was represented by a specific value of current defined by a resistor supplied by the stop key when it was switched on. A current-summing mechanism then selected an appropriate combination of pedal stops depending on the magnitude of the summed currents. The whole thing was actually an elementary electromechanical computer from today's viewpoint, and it provides a remarkable insight into the power of Hope-Jones's fertile mind. Because there is evidence that the system was implemented and that it worked, at least in some of his American organs, it was a noteworthy achievement for its time.

It is possible that the organ at St Paul's, Burton upon Trent (1894) was originally fitted with a suitable bass arrangement which was removed subsequently. Close inspection of the combination action in the surviving console shows that the traces (drawbars) which were actuated by the pedal stop tablets each have a pair of holes at the rear. These could have been connected to a suitable bass mechanism which moved the pedal stops automatically in the manner just described. The drillings can be discerned in Figure 22. It is probable that the combination action in this console was modified at one or more of the rebuilds which took place between 1906 and 1925, if only because the thumb pistons and toe studs seen in Figure 21 look unlike those which Hope-Jones himself used in other consoles in Britain.

There were probably parallels with the pneumatic system devised by Casson which he called "pedal help". Despite an earlier association, Casson and Hope-Jones later became adversaries and the acrimonious correspondence conducted publicly in the musical press suggests that an element of plagiarism in one direction or the other might have been involved. What Casson seemed not to understand was that the protection offered by a patent, though well defined, is somewhat limited in scope. A patent cannot be granted merely for an idea but only for a practical embodiment of it. Therefore anyone can come along, take up an idea from somebody else's patent, re-implement it in a sufficiently novel manner, and then get their own patent to cover it. This aside, it is doubtful whether Casson (a former bank official and little more than a seat-of-the-pants amateur enthusiast) could have held a candle in any event to Hope-Jones (a professionally accredited electrical engineer) in matters such as these, especially where electricity was concerned.

As with some other inventions of Hope-Jones, such as mobile consoles on the end of a ludicrously long cable, the organ world probably grew tired of his suitable bass system in its most advanced forms. Today we merely couple the pedal and manual stops together when we wish to control both at once and uncouple them otherwise, even though it would now be almost trivially easy to implement his "smart" suitable bass systems using computer control. A century or so ago there was clearly a significant proportion of organists who demanded the latest gadgets, not so much because of what they offered but simply because they were the latest. Nowadays most players deem it more important to select the pedal stops themselves rather than have a machine do it for them.

Reversible pistons

Reversible stops (those which reverse their current state when a piston or pedal is operated) were already in common use in Hope-Jones's day, so it would not be surprising if he used them as well. Rather, it would be surprising if he did not. Like some of his combination actions described already, a reverser makes use of a bistable mechanism which can adopt one of two stable states. The surviving console from St Paul's, Burton (Figure 21) has a thumb piston in the great keyslip and a toe stud which apparently worked a reverser to the great to pedal coupler. The associated mechanism is visible in Figure 22 as the horizontal piece of wood shaped like a spanner (wrench). This forms part of an electropneumatic 'poppet' mechanism, connected to the rear of the trace corresponding to the great to pedal stop tablet by means of the metal bracket which can be seen in the photograph. However, as this console was probably modified on at least one occasion, it is possible the reverser was a later addition. Nevertheless, mechanical and pneumatic poppet actions were commonly used by organ builders in the late Victorian era, so it is indeed possible Hope-Jones merely went one stage further by making them work electropneumatically. He would also have been able to construct a fully electric reverser circuit using a pair of ordinary relays by drawing on his electrical engineering background, though I have yet to find firm evidence that he did. Such circuits became commonplace during the twentieth century in one form or another, and electromechanical reversers of this type using two electromagnets are still manufactured today. An alternative circuit using two standard relays is described in reference [47].

What systems did he actually use?

Hopefully some idea of the welter of putative combination mechanisms which Hope-Jones could, in theory, have used will be apparent from the foregoing. However it has been emphasised several times that the material described in patents can be very different to the embodiments actually used, and in Hope-Jones's case this was often true. On the whole his patents were skilfully drafted so that their claims covered as wide a field of application as possible while giving away the minimum amount of useful information, and even some of that was often misleading or downright wrong. Apart from the electropneumatic systems known to have been employed in a few organs such as that at Battersea Town Hall, I have little firm evidence about what might have been used elsewhere in his British organs. Nevertheless, the other methods he actually did use would probably have been similar to some of those just described, and together with the limited amount of collateral information we have, it is possible to compile a list of their probable attributes:

1. The stop tablets or stop keys were almost certainly motorised (self-indicating) in the vast majority, if not all, of his organs. Hope-Jones himself repeatedly expressed a preference for this system in his patents and other literature. In some cases we have first hand accounts from other writers which also say this was the case (e.g. the McEwan Hall [33] and several other organs both in Britain and America [40]).

2. The motorised stop actions were almost certainly electrically or electropneumatically (i.e. not mechanically or pneumatically) implemented by means of circuits switched directly by the pistons, or via relays (electromagnetic or electropneumatic) controlled by them. Although purely mechanical and purely pneumatic mechanisms were described by Hope-Jones as we have seen, it is inconceivably difficult to see how these could have been integrated with the complex systems which he designed into his organs from the outset if motorised stops were used. For example, his first organ at St John's, Birkenhead had "suitable bass" and "independent pedals" options. Subsequent instruments also had "suitable couplers" or even "suitable accompaniments" (to solo stops) integrated into the scheme. On top of this were novel controls such as his three-way compound composition keys. As

mentioned previously, he described in his various patents the decidedly non-trivial circuits and special components necessary for these and similar mechanisms to function.

3. If we concede the reasonableness of the above two statements, then either electropneumatic or purely electric stop actuation mechanisms could have been used in Hope-Jones's fixed consoles. However in his detached and mobile ones on the end of a long cable, it is difficult to see how wind could have been provided. In these cases one is left only with a purely electric option for stop tablet actuation, despite the difficulties of providing the significant power necessary for it to function. A hybrid dynamo-plus-accumulator system has been conjectured as being suitable and economical for this purpose.

   If this conclusion is rejected, or if subsequent information turns up in the future which shows it to be wrong, then the range of functionality of the combination actions in his consoles which has been assumed would need to be degraded. For example, we would need to consider whether a blind or partially blind combination system was used instead of a fully motorised one, particularly when systems such as "suitable bass" were activated by the player.

Swell Shutter Actions

Both in the UK and subsequently in the USA, Hope-Jones continued to devote much effort to the problem of controlling the shutters (shades) of a swell box remotely by electricity. As far as this article is concerned which deals only with his work in Britain, it is doubtful whether most of the techniques in his patents ever saw the light of day. Therefore they will not be described in detail because there is no merit in merely reproducing material which can be obtained elsewhere. Here, what matters more is what he actually did in Britain rather than what he might have done or did subsequently in America. The quest for the methods he used for swell box control in his detached consoles on the end of a long cable is particularly intriguing, and this means that yet again we have to start at the beginning with his prototype instrument at St John's, Birkenhead. Nevertheless it is useful to first review his thinking briefly in terms of the principal innovations described in his various writings and utterances.

Appearing in his early (c. 1890 and later) patents both here and in America are two techniques which can reasonably be classified as servomechanisms, because the position of the swell shutters depends on an error signal derived from the shutters themselves and the position of the swell pedal. In response to a demand from the pedal the shutters then move until the error signal vanishes or is minimised. Moreover, in today's terminology one of the techniques is unquestionably digital and the other analogue. Both are elegant expressions of the thinking of a professional engineer with a fertile mind, comparable with the fully pneumatic servomechanisms originated by Vincent Willis in about the same era.

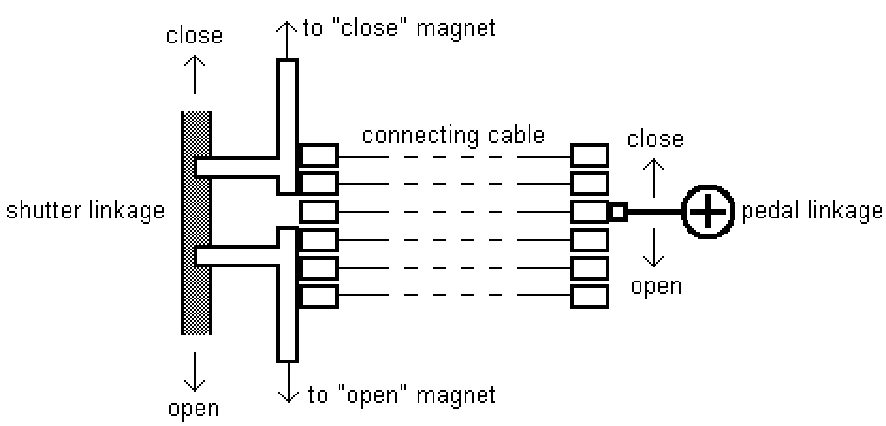


Figure 30. "Digital" swell action
(Copyright © Colin Pykett)

Illustrated in Figure 30, the "digital" technique has the swell pedal operate a stud or leaf switch which energises one of a number of wires at a time in the connecting cable. Only six studs are shown, and in practice a greater number would have provided finer control. Note that this is a highly simplified version of the obscure original which, in common with many Hope-Jones drawings, would have been almost incomprehensible to the majority of his readership. At the organ end of the cable is a similar switch with an ingenious two-segment wiper operated by the swell shutter linkage, the parts being separated by an amount equal to the separation of the studs.

All the shutters are linked mechanically and two large pneumatic motors control them electropneumatically, one to open and the other to close them. Each part of the wiper is connected to one of the electromagnets controlling these motors. The shutters will therefore continue to move in one direction or the other until the gap between the two wiper segments coincides with the energised stud, at which point the circuit is broken and movement ceases. This technique has echoes yet again of Hope-Jones's familiarity with the developments then being undertaken for advanced telephony in pursuit of automatic dialling, in which an essential requirement was for switches which would seek a currently free circuit among the many busy ones in an exchange. Such switches eventually became the uniselectors used in Strowger-switched exchanges for the next hundred years or so. If you have ever seen a uniselector looking for a free circuit you could well be reminded of Hope-Jones's automatic swell engine wiper switch.

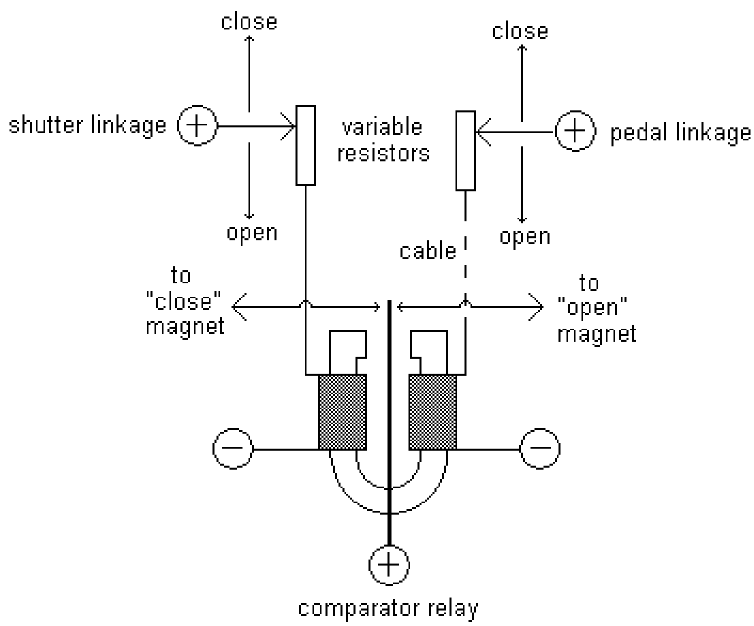


Figure 31. "Analogue" swell action
(Copyright © Colin Pykett)

The "analogue" technique is illustrated in Figure 31, again in simplified form. Potentially it provided more precise control of the shutters in that it was not limited to the relatively small number of discrete positions in the system just described. Moreover that control was achieved via a single wire in the connecting cable in which the current was continuously variable, rather than the multiple wires of the previous arrangement in which the signals were binary (either on or off, high or low, all or nothing).

As before, all the swell shutters are ganged together mechanically and controlled electropneumatically by two large motors, one to close and one to open them. Both the pedal and the shutters operate a wire-wound rheostat or variable resistor, each of which is connected to a separate winding on a comparator relay. When the currents flowing through both windings are equal a moving contact sits between a pair of fixed ones and no circuit is made, but if there is a significant imbalance in the currents the moving contact closes one circuit or the other and thereby inflates one of the large shutter motors. Therefore a movement of the swell pedal alters the current flowing through the corresponding coil of the relay, and this causes the shutters to move until the current is equalised in the other coil.

Although both methods are ingenious and appear straightforward at first sight, they would have been prone to several problems which can afflict all servomechanisms. One would have been due to the significant inertia of the swell shutters which could have caused overshoot and a consequential "hunting" problem as the system oscillated around the correct shutter position. It is significant that in his later work Hope-Jones developed means to brake and thereby damp the shutter movement if they moved too quickly (which also prevented them from audibly slamming shut). Another potential problem would have been hysteresis, most likely to arise in the comparator relay of the "analogue" system, in which the shutters might not have responded to the first movement of the swell pedal because of the fact that static friction exceeds sliding friction in most cases. This would have necessitated moving the pedal by an unexpectedly large amount just to get things moving inside the organ – many electropneumatic swell engines still suffer from this problem today. Therefore it is perhaps not surprising in view of such practical difficulties that he later moved to the system for which he is best known in which each shutter simply has its own electropneumatic action, controlled by an individual contact in the pedal mechanism so that each shutter is either fully open or fully closed. In its final form in which the shutters were also of graded sizes, this became the method used in Wurlitzer theatre organs.

But here we are interested in the techniques used in Britain before Hope-Jones emigrated to America, and a certain amount of inference is necessary to get at the probable answers by looking at the collateral information we have. The organ at St John's, Birkenhead had a stop tablet labelled "swell shutters" which opened the swell box fully when activated (see Appendix 1). The same function was also implemented by one of the sforzando pedals [21] and in both cases the shutters would return to their former position when the chosen override switch was no longer active. The description of the system in this account [21] from the player's point of view is somewhat confusing however. It mentions *"the swell pedal, which has the combined advantages of the balanced and self closing systems"*, and elsewhere *"two pedals are arranged, one within the other, in such a manner that a crescendo or diminuendo of the stops may be obtained whilst both hands are engaged upon the manuals"*. On the basis of these statements alone one is little the wiser.

Fortunately, but only if we believe him, Hope-Jones himself dispelled these and other uncertainties during his 1891 lecture to the College of Organists [7] in which he said:

"The swell pedal, which I prefer to make self-closing, is returned to its position by a spiral spring only, so that its movement is not in any way impeded by the inertia of the swell shutters and connecting mechanism. On this account it responds more readily to the organist's wishes. By the employment of varying electrical resistances there is no difficulty in securing simultaneous and synchronous movement of the pedal and the shutters, and this may readily be managed through a single wire. The swell pedal,

though self-closing, will remain in any position if the slightest pressure tending to move it towards the left be exerted. A touch in the opposite direction will liberate and allow it to close. The pedal cannot remain in a middle position, but will spring either right or left. Its sideway [sic] *movement is very slight. A stop-key may be provided, with those governing the registers on the swell organ, which will open the swell box without the necessity of touching the pedal. Such a stop-key must however be automatically thrown out of action as soon as the foot touches the pedal. In this manner the swell shutters are always amenable to the pedal, though it is possible for the organist, when sweeping his finger along to bring out "full swell", to open the box also, should he desire to do so."*

This explains the twin phenomena of a swell pedal having the "combined advantages of the balanced and self-closing systems", and of two pedals "arranged one within the other". The account also makes clear that the mechanism referred to is that already described, in which the pedal and the shutters operate variable resistances and in which there is only a single interconnecting wire, as in the circuit of Figure 31. Given the date of the lecture, which took place so soon after the Birkenhead organ had been unveiled to the world, one can perhaps assume that Hope-Jones used this type of servomechanism to control its swell shutters.

Only a few years later, by 1894 at the latest, the story had probably changed however. Although we still find the stop tablet which throws open the shutters at St Paul's, Burton upon Trent, we also know about a relay labelled "swell shutters" buried deep inside this organ. This is significant.

Figure 32. "Swell Shutters" relay label at St Paul's, Burton upon Trent
(Copyright © Lancastrian Theatre Organ Trust)

Pictured in Figure 32, this label is on the rear of the relay cabinet whose front view was shown earlier at Figure 12 and it shows that one of the electropneumatic ladder relays in this instrument was used for this purpose. This means we can definitely discount the use of the "analogue" control system outlined earlier, because there is no point in that circuit where a multipole relay can play a sensible role. We can also probably discount the "digital" system for the same reason because forcing all wires simultaneously high (or low) with such a relay would be a situation that could not occur in normal use – either the "open" and "close" magnets would both be energised at the same time or neither of them would be energised. In both cases this would result in unpredictable operation. In both the "analogue" and "digital" cases only an ordinary single-pole/single-throw switch or relay would be required to override the servo and open the shutters, and it would simply be connected to the "open" magnet of the shutter mechanism. When the override switch was opened again the shutters would return to their former position, as required, by the action of the servo. The probable use of a multipole ladder relay at Burton therefore suggests that Hope-Jones had moved to the use of individual actions for each shutter as early as 1894, though a multi-stage machine such as a whiffle tree cannot be ruled out. In either case it would have been necessary to apply power simultaneously to each shutter magnet when the override switch was activated, requiring the use of this type of relay.

Individual actions to each shutter would also have required a particular form of swell control at the console in which power was applied successively and cumulatively to each shutter action as the pedal moved, with the power remaining applied until the pedal was moved back again. The switching arrangement at St Paul's, Burton upon Trent, shown in Figure 33, was of this type. The stepped brass contacts can be seen, and there was another set out of shot at the extreme left of the picture. The sliding brass wipers, attached to the wooden actuator, moved vertically across both contact arrays as the swell pedal was operated.

Figure 33. St Paul's, Burton – swell pedal contacts (1894)
(Copyright © Lancastrian Theatre Organ Trust)

An electrically similar system was still being used a few years later in the organ at St Modwen's, also at Burton. Illustrated in Figure 34, the build standard of this flimsy and amateurish arrangement contrasts unhappily with the robustness of the mechanism seen earlier at St Paul's. The difference might be explained by the fact that the organ at St Paul's was built by Hope-Jones's own company whereas that at St Modwen's was a Hope-Jones style instrument by Norman and Beard (i.e. similar in this respect to that at Battersea Town Hall). However the situation is further complicated by two rebuilds of the St Paul's organ which were undertaken by Norman and Beard in 1906 and by Hill, Norman and Beard in 1925. Apparently the first of these involved replacement of the swell contacts, though whether this related to those in the console or in the organ itself is not known (there would probably have been contacts inside the organ associated with the swell mechanism to enable Hope-Jones's usual power saving system to have been applied). Nevertheless, taking the evidence here at face value, one can perhaps begin to understand why he distanced himself so often from the sometimes unfortunate results achieved by his licensees when using his system.

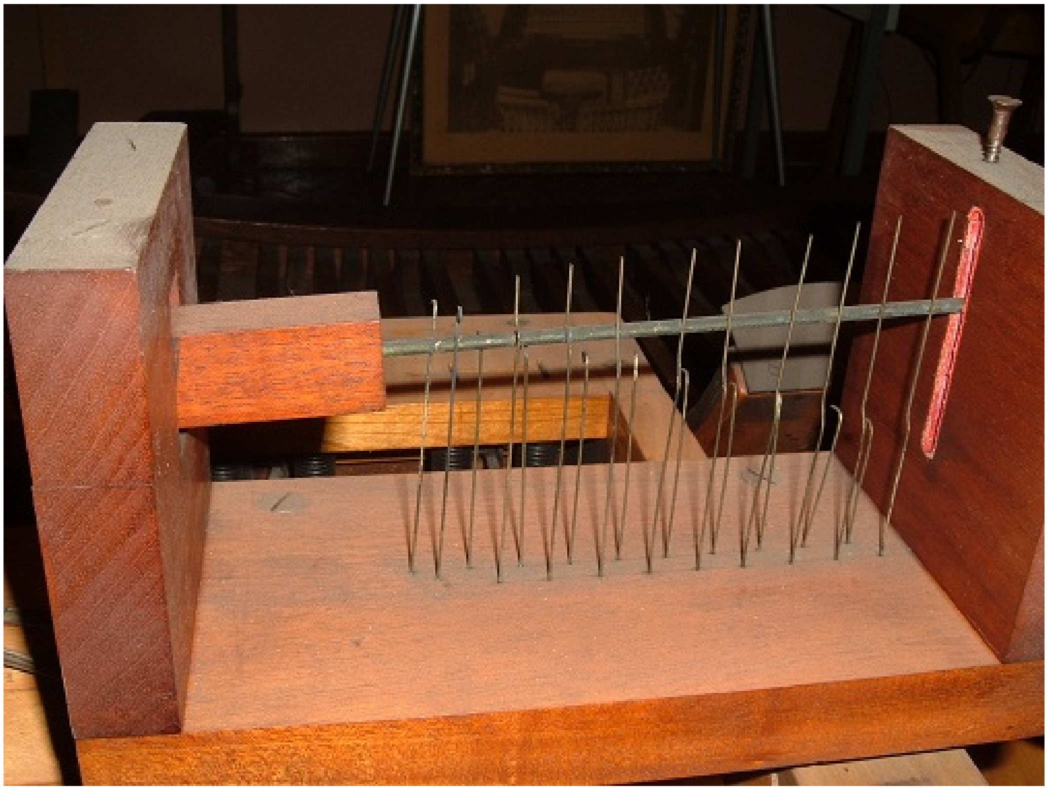


Figure 34. St Modwen's, Burton – swell pedal contacts (1899)
(Copyright © Lancastrian Theatre Organ Trust)

As time went on, it seems that the enthusiasm for moveable detached consoles on the part of all organ builders and their customers waned as the novelty simply wore off. In the case of Hope-Jones they required special techniques for their coupler and combination actions as described in previous sections of this article, and it has been shown that this would have made it difficult to power the organs using batteries as well as being unattractive from a production viewpoint. Their necessarily electric swell actions might also have been unreliable, however they were implemented, because some organs whose consoles were originally moveable were later modified to use a mechanical swell action and in those cases the console obviously became fixed in position thereafter. This happened at Pilton for example. Towards the end of his life in America Hope-Jones seems to have revisited mechanical linkages, though with a typically complex realisation, because he developed a servo-assisted system which allowed the player to retain full control over the shutters while reducing the amount of force necessary to operate the pedal [37].

The 'Master Reset' problem

Previous chapters have described several bistable electropneumatic mechanisms – those with two stable states, 'on' and 'off'. Summarising, they include:

- The power saving system applied to the speaking stop sliders. The mechanism was double-acting using two electropneumatic machines, one to push the slider in one direction and the other to pull it back again. The slider operated a changeover switch which routed power to the appropriate magnet when the stop tablet (also a changeover switch) was next toggled. The switch was also designed so that both magnets in the slider machines no longer drew any power when the slider had reached its operating position in either direction.

- A similar double-acting system applied to the coupler or unit chest ladder relays – once a relay had changed state in response to a demand from a stop tablet its magnets no longer drew power.

- The electropneumatic bistable combination action in some organs.

A characteristic feature of these systems is that their states existing inside the organ ('on' or 'off') will persist when the instrument is switched off. Thus they are non-volatile, which can lead to problems. For instance, after the organ is switched off, the organist might then decide to manually cancel all the stop tablets, or anyone else might come along and capriciously mess around with them at the console. In this situation the result would be that the previous correspondence between the console controls and the internal state of the organ would have been lost when it was next switched on.

It might be argued that this should not matter. After all, the mechanisms inside the organ should react correctly to whatever console control states exist when power and wind are next applied, thus sliders should move and relays should toggle to mirror the new stop tablet settings. However there is evidence that this happy state of affairs was not simple to achieve. In practice it is likely that the internal mechanisms would not behave as expected and required when the wind pressure was building up slowly at switch-on, together with a similarly slow build-up of action voltage if it was provided by a dynamo. Even in normal operation the power saving changeover switches in particular would have demanded careful adjustment and regular maintenance under conditions of stable wind pressure if they were to be reliable. Yet there could be no guarantee that they would work properly under the unpredictable conditions existing during switch-on. For instance, it is possible that a 'sticky' slider moving sluggishly while the wind pressure was still low could cease to move altogether, leaving its changeover switch in some intermediate position where the corresponding magnet continued to draw power. Additionally, in such an intermediate position the switch might become open circuited to both 'on' and 'off' demands from the stop tablet. In this situation the associated stop would become unusable until the slider was shoved manually by someone crawling into the interior of the organ. Similar conditions could arise with the note-switching relays.

Another problem concerns the key action magnets. It was remarked in an earlier chapter that every note is, in effect, 'on' while the organ is not in wind because all the disc valves will be resting under gravity on the magnet poles. Therefore all the pallets on a bar and slider chest could try to open momentarily while the wind pressure was building up. Consequently many pipes whose stop sliders had remained ‘on’ by virtue of the arguments above might cipher, if (hopefully) momentarily. Similar problems could arise in unit chests where each pipe has its own action. And both valves of the magnets in all bistable mechanisms such as relays and slider machines would initially be ‘on’, a prohibited condition which would not arise in normal operation. This could lead to unpredictable operation at switch-on. These problems would be exacerbated by traces of residual magnetism in the magnet cores, which would increase the delay before the rising wind pressure would be able to blow the disc valves off the magnet poles towards their seat against the exhaust tubes of the action magnets, thereby turning the valves ‘off’ as required.

Some, but not all, of these unpleasing situations could be prevented by organists developing the discipline of cancelling all the stops before switching the organ off, though they might not always oblige and visitors might be unaware of the custom. In any case, manual cancellation would often have been necessary as by no means all Hope-Jones organs had a ‘general cancel’ piston. Thus stop cancellation could have been tedious on a large instrument. Therefore these problems might explain the ‘master reset’ system applied to some of Hope-Jones’s organs. It was a complex scheme comprising several features, one of which was a large multi-contact switch similar to a ladder relay. This was operated, not electropneumatically as in the case of a coupler relay, but mechanically by the rise and fall of a wind reservoir. Its function was to momentarily reset a large number of bistable mechanisms such as slider machines to the necessary ‘off’ position either at switch-off or switch-on (or both). Other features of the resetting system included:

- Ventil valves controlling the wind supply to unit chests so that wind did not enter until all the note magnets had had enough time to assume their ‘off’ state.

- A backup power supply to provide the full action voltage to the entire organ immediately at switch-on to avoid problems due to the slow build-up of voltage from a dynamo. This transient backup power was obtained from a battery of large dry cells, which would last for a long while since they were only called upon momentarily for a few seconds at a time. There was an associated master power switch which selected either the ‘battery’ or ‘dynamo’ option to power the organ – batteries were used at switch-on for a period long enough to enable the organ to reset itself, whereupon the dynamo took over. The power switch itself was operated automatically from a rising wind reservoir. (It is interesting to speculate whether the visible presence of the dry cells led to the widely-held belief that Hope-Jones’s organs were actually powered by them more often than they were in reality).

Yet further features were incorporated into the design of the bistable mechanisms themselves. For instance, the primary pneumatic valves providing the ‘stop off’ function in the slider machines were mechanically preset to favour the ‘off’ position by means of a light wire spring. The springs can just be discerned in Figure 17 which illustrates some of those in the Battersea Town Hall organ.

Not all of the features mentioned above were necessarily used in all of Hope-Jones's organs, nor does the description cover all the techniques he used. But sufficient has been said to demonstrate that a more or less complicated 'master reset' system was essential in most if not all of his instruments. It was conceptually identical to the system used today in all digital systems incorporating bistables, where a 'MR' pin is frequently found on chips containing bistable circuits. This has to be toggled momentarily by a voltage pulse whenever the system is powered up otherwise it will not work at all. It is therefore fascinating that Hope-Jones had anticipated the need for a resetting function in his organs, and that they used non-volatile bistable mechanisms which consumed zero continuous power, many years before the word 'electronics' had even been invented.

In writing the above I have been indebted to Lucien Nunes for providing details of the resetting system discovered in the Hope-Jones/Norman and Beard organ at Battersea Arts Centre (formerly the Town Hall) when it was being dismantled in 2013 prior to a rebuild. As with some other information in this document, it is fortunate that the material was recorded for posterity in view of the disastrous fire in 2015.

Conclusions

Hope-Jones's organ of 1889 at St John's, Birkenhead hit the organ world suddenly and hard. Widely visited, it quickly became famous and at once established him as an organ builder of international repute even though his pedigree in the craft was non-existent. Tonally it was unremarkable because it was a rebuild of an existing instrument, and in this it was also unique because there are few organs by Hope-Jones of which this can be said. It was solely its novel electric action which caused the stir because it enabled the use of a small and mobile detached console together with many novel playing facilities. This article has shown that it was the first organ in the world whose action was designed from the outset as an integrated *system* by a gifted professional engineer, using electricity to control not only the key action but the speaking stops, couplers, pistons and swell shutters as well. One of the key elements facilitating and illustrating the integration was Hope-Jones's action magnet, whose design was subtle and which is discussed at length in the article. However one aspect on which no light could be cast was that Hope-Jones must have been developing his ideas for some years before he became associated with St John's in the first place, and part of this development must have involved a fair amount of practical experiment and testing. It is inconceivable that such a ground-breaking instrument could have been put together in working form in so short a time merely through a few conversations between himself and Franklin Lloyd. We shall probably never know much about the technical antecedents which led to the organ at St John's.

The article has also traced the evolution of Hope-Jones's subsequent thinking and practice over the years until he left for America in 1903. His key actions remained fairly static, consisting of one or two pneumatic amplifiers controlled by his action magnet. However his speaking stop actions evolved progressively from organs in which all stops were on slider chests to those in which some ranks were conceived on the unit principle. The progression was nevertheless fairly slow considering that Hope-Jones had completed his paper design for the fully unified organ by 1890 at the latest, and it has been suggested that this was due to a mixture of technical and commercial considerations. There is little doubt that the power supply limitations of the day prevented him building the power-hungry unified organ with its hundreds or thousands of individual pipe actions, and he was probably not in a position to have manufactured them economically in any case.

Hope-Jones introduced several techniques for coupling, of which his electropneumatic ladder relay was undoubtedly the prototype for that used in the Wurlitzer theatre organ many years later. The article has described the design features of this in detail. He also used relays of a different design in his mobile and therefore remote consoles because wind would not have been available. Likewise he also used both electropneumatic and (probably) electromagnetic stop combination actions depending on whether the console was mobile or not, and these were both discussed. Of the many swell shutter control techniques which he invented throughout his career, there is some evidence that he was using individual electropneumatic actions for each shutter as early as 1894.

Although the organ at St John's, Birkenhead used a dynamo to supply the action current, Hope-Jones devoted much subsequent effort to minimising the power consumption of his organs and some of his techniques have been described in the article. This was forced on him because of the need to establish a customer base in the majority of the country which did not enjoy access to mains electricity, town gas or high pressure water for blowing the instruments and thus for driving a dynamo also. In these cases he had to use accumulators and some of his later organs would also have run for limited periods on a battery of dry cells, though definitely not on a single cell as he loudly and frequently claimed. In all of this he was at a disadvantage because of the low resistance of his action magnet and thus its high power consumption relative to those of his competitors. It is unfortunate that he degraded himself by the shrillness and mendacity with which he insisted the opposite was the case.

With the exception of unit chests and their means of control which appeared only a few years later, the 1889 organ at Birkenhead contained all of the action, switching and circuit techniques which were immediately taken up and applied in electric actions worldwide. They were not displaced until electronics began to appear in organ building in the 1960's, and even today organs are built or rebuilt using electromechanical actions and components which are functionally identical to those invented by Hope-Jones. This remains the measure of his legacy and achievements.

oooOOooo

protest shd be made regarding that impudent charlatan's doings at Worcester; as you know, he has only been a kind of sewer-maker between 'pipe' and 'key'
W T Best (concert organist, letter, 1895)

whatever else he might have been, he was certainly no charlatan
W C Jones (voicer, no relation)

Notes and References

Much of the material listed below is difficult to obtain today for one reason or another, most often because of its age. Therefore some notes have been included which might assist readers to decide whether seeking copies will be worth the cost and effort. Please note that I cannot offer any assistance in obtaining this or any other reference material.

1. See *http://www.ltot.org.uk/* (accessed on 4 May 2020).

The website of the Lancastrian Theatre Organ Trust in Eccles, Manchester, UK.

2. "The World Around Hope-Jones", D Hyde, 2007.

Available at:
http://www.ltot.org.uk/vox25.pdf and *http://www.ltot.org.uk/vox26.pdf* (accessed on 4 May 2020).

The late Don Hyde of the Lancastrian Theatre Organ Trust was awarded the Simonton Literary Prize by the American Theatre Organ Society for this paper.

3. See *https://www.taylor-hammond.com/about-us.html* (accessed on 4 May 2020).

HWS Associates LLP were restoring the Norman and Beard/Hope-Jones organ at Battersea Town Hall (now the Arts Centre) when this article was first drafted in 2009 but the firm was dissolved after the death of one of the partners. Taylor-Hammond Associates Ltd was formed subsequently in 2012 to carry on this and similar work, such as the restoration of the large Compton dual-purpose organ at Southampton Guildhall with its twin four manual "theatre" and "classical" consoles.

4. See *http://www.electrokinetica.org/* (accessed on 18 May 2009; unavailable on 17 February 2021).

Lucien Nunes founded the Electrokinetica museum, and he has also been intimately involved with the restoration of the Battersea Town Hall and Southampton Guildhall organs (see [3] above).

5. "From Wirral to WurliTzer", Roger C Fisher, Classfern, 2001. ISBN 0-9532991-9-8.

A readable and enjoyable book containing some previously unknown facts about the life and work of Hope-Jones. It also chronicles the story of the organ at St Luke's church, Tranmere which was originally purchased and installed by Hope-Jones while he was still employed as a telephone engineer. Mr Fisher rescued this instrument just before the church was demolished in 1972.

6. Ignoring those which were subsequently voided, the successful British patent applications by Hope-Jones during the period between his resignation as a telephone engineer and the formation of his first company were (number/year): 15245/1890, 15461/1890, 18803/1890 and 18073/1891.

At the time this article was written these documents had yet to be digitised by library services in the UK and consequently they are difficult to obtain. Much original material from this era is now so fragile that it can no longer even be photocopied, being bound in huge leather volumes which are unfortunately disintegrating. The paper itself is also in a very delicate state. Only a few copies now remain intact and they are difficult to track down. This potential for the irrecoverable loss of part of Britain's technical heritage in the near future, which includes Hope-Jones's legacy of course, was one of the reasons which prompted the writing of this article.

7. "Electrical Aid to the Organist", R Hope-Jones, *Proceedings of the College of Organists*, 5 May 1891.

As far as I am aware photocopies of this article are still available from the Royal College of Organists. It was a transcript of a lecture which I have discussed in detail at:

www.colinpykett.org.uk/hope-jones_at_the_college_of_organists.htm

8. "System of Electric Organ Control", R Hope-Jones, 1892.

A pamphlet privately printed by Hope-Jones which is now difficult to get hold of.

9. "Hope-Jones and the Dry Cell, C E Pykett, 2003.

www.colinpykett.org.uk/hope-jones_and_the_dry_cell.htm

10. "Organs and Tuning", Thomas Elliston, Weekes & Co, London, 1894.

A fascinating book which is still relatively easy to obtain from second hand book shops or from Amazon, eBay, etc. However it was written by an enthusiastic though somewhat naive amateur, thus much of it is unreliable as a scholarly or historical source.

11. "Hugh Blair: the Battersea Years (1900-4)", Robert Evans, Church Music Society, 2006.

This article may also be available on the CMS website.

12. "The Evolution of Electric Actions", C E Pykett, 2005.

www.colinpykett.org.uk/the_evolution_of_electric_actions.htm

13. The residual magnetism problem was mentioned in Harrison and Harrison's technical report (written by Arthur Harrison, dated 2 December 1921 and deposited in the Library of Worcester Cathedral) on the state of the Hope-Jones organ at Worcester cathedral. Harrison also mentioned that the insulation of the cables had perished and the wiring was badly burnt.

14. "The Art of Organ-Building", George Ashdown Audsley, New York, 1905.

A detailed though excessively pedantic survey of organ building in two volumes, written by an architect whose unawareness of his limitations is continually amusing. Perhaps the best description of the work is that it is good in parts, and one has to exercise judgement in extracting material from it. As would be expected of an architect though, most of the diagrams and drawings are exquisite. Most references to Hope-Jones's actions are in the chapter entitled “Electricity in Organ Building” in volume II. It is available in facsimile from Dover.

15. Hope-Jones’s action magnets usually had a coil resistance around 50 – 60 ohms. This contrasts with the magnet resistances of 250 – 550 ohms advertised by T C Lewis for his electropneumatic organs such as those at St John’s, Upper Norwood (1882) and St Botolph, London (1893). Hope-Jones never seems to have admitted that his magnets were of such a low resistance, instead repeatedly claiming both verbally and in his patent specifications etc that the opposite was the case.

16. “The History of Electric Wires and Cables”, R M Black, Science Museum (Great Britain), 1983.

17. “The organ in the Usher Hall, Edinburgh”, John Kitchen and Duncan Matthews, *Organ Building*, Institute of British Organ Building, (4), 2004.

Organ Building is the house journal of the IBO and it can be difficult to obtain back numbers, presumably because of the limited print runs to serve such a small and specialist audience. Most of the articles are written by IBO members themselves who would therefore not be expected to criticise each other in print. Consequently there is a self-congratulatory flavour about the whole affair, which sometimes seems little more than the magazine of a mutual admiration society. For these reasons one should not always take what is said at face value.

18. Data kindly provided by Lucien Nunes for the Battersea Town Hall organ, various private communications, 2008/9.

19. The Hope-Jones Electric Organ Company Ltd, Order Books 1892 to 1904, British Organ Archive, Birmingham.

Material held at the British Organ Archive is open to inspection by the public.

20. “The Organs of Worcester Cathedral”, Colin Beswick, Dean & Chapter of Worcester, 1967.

The late Canon Beswick was Precentor and Sacrist of Worcester Cathedral when he wrote this pamphlet in 1967. It was published by the Cathedral itself and may now be difficult to obtain. Beswick was no fan of Hope-Jones; his polarised views coloured what he wrote quite strongly which calls into question some of his conclusions.

21. *Musical Opinion*, 14, March 1891.

Material from journals of this age is often difficult to obtain for similar reasons to those pertaining to old patent specifications (see [6]).

22. “The Hope-Jones Organ at St. Paul’s, Burton upon Trent”, Relf Clark, *Organists’ Review*, March 1991.

One of the few articles published in the open literature as a result of Relf Clark’s comprehensive research (see [38]). It does not cover technical aspects in much detail however.

23. *The Musical Standard* vol. XL no.1388 7 March 1891

Material from journals of this age is often difficult to obtain for similar reasons to those pertaining to old patent specifications (see [6]).

24. *The Musical Standard* vol. XL no.1390 21 March 1891

Material from journals of this age is often difficult to obtain for similar reasons to those pertaining to old patent specifications (see [6]).

25. See *http://www.mosi.org.uk/media/33871757/bisschopgasengine.pdf* (accessed 29 May 2009; unavailable 4 May 2020)

A page from the website of the Museum of Science and Industry in Manchester.

26. "The Hope-Jones Organ at Pilton Parish Church", C E Pykett, *Organists' Review*, November 1993

Also available at:
www.colinpykett.org.uk/the_hope-jones_organ_at_pilton.htm

27. "The Organ", Peter Williams and Barbara Owen, Macmillan, London, 1988.

This book was written by two eminent musicologists specialising in the organ both in Britain and America. It makes clear a certain narrowness of outlook in that not only did they dislike what Hope-Jones did but also electric actions in general (*" in practice they* [electric actions] *satisfy only those builders whose tonal ideals, like their instruments, are virtually outside the realm of true organs"*). Its treatment of Hope-Jones therefore has to be regarded circumspectly.

28. "The History of the English Organ", Stephen Bicknell, Cambridge, 1996

Hopefully the Scots, Welsh and Ulstermen will forgive the late Stephen Bicknell for his exclusive focus on their old adversary. In fact it seems to be purely a slip which neither he, his publishers nor their reviewers apparently picked up because he does of course stray beyond the English border in this excellent treatise. His coverage of Hope-Jones, though necessarily brief in the context of such a large remit, is written objectively and with understanding. The only disadvantage of the book is its price.

29. See, for example, Clark 1993 ("An Apparently Controversial Instrument", Relf Clark, *JBIOS* 17, 1993, Oxford, p.59).

One of the few articles published as a result of Relf Clark's comprehensive research (see [38]). *JBIOS* (Journal of the British Institute of Organ Studies) is only distributed to BIOS members so it can scarcely be regarded as part of the open literature, though back numbers may be available. It does not cover technical aspects in much detail however.

30. "Re-creating Vanished Organs", C E Pykett, 2005.

www.colinpykett.org.uk/re-creating_vanished_organs.htm#Pilton

31. "The Organ Today", Herbert Norman and H John Norman, Barrie and Rockliff, London 1966.

An interesting and readable account of the main issues involved in organ building by two members of the former well-known organ building dynasty, though it reflects a style which is rather complacent, dated and chauvinistic. It is descriptive and qualitative rather than numerical and quantitative, and this is not a criticism. However one comes across some facile statements from time to time, which is surprising considering the background of the authors. The contents are also exasperatingly muddled in places, typified by the paragraph on the relative merits of tracker action which concludes the section on reed voicing! The neo-gothic drawings are curious and some are obscure.

32. National Pipe Organ Register (NPOR) entry at:
http://www.npor.org.uk/cgi-bin/Rsearch.cgi?Fn=Rsearch&rec_index=N17247
(accessed 5 May 2020)

The NPOR is a laudably comprehensive database of most of the pipe organs in Britain.

33. *The Student*, December 1897.

Material from journals of this age is often difficult to obtain for similar reasons to those pertaining to old patent specifications (see [6]).

34. "Organ Construction", J W Hinton, London 1900.

Difficult to come by today other than in facsimile form in which many of the diagrams and some of the text reproduce badly.

35. "Response Speed of Electric Actions", C E Pykett, 2001.

www.colinpykett.org.uk/response_speed_of_electric_actions.htm

36. "Handbook of the Organ", J Matthews, Augener, London c.1900

Difficult to come by today other than in facsimile form in which many of the diagrams and some of the text reproduces badly.

37. US patent 1,021,149, 1912.

38. "Robert Hope-Jones MIEE: An interim account of his work in the British Isles", Relf Clark, doctoral dissertation, University of Reading, February 1993 (unpublished).

A comprehensive two-volume PhD thesis which unfortunately has not been published in anything approaching a complete form as far as I know. It can be inspected by appointment in the library of Reading university but cannot be borrowed. Elsewhere Clark has extracted and published a few aspects of his research relating to particular Hope-Jones organs, and these have appeared from time to time in various journals such as *Organists' Review* and *JBIOS* (Journal of the British Institute of Organ Studies). Two examples are quoted above at [22] and [29]. *JBIOS* is only distributed to BIOS members, though back numbers may be available. It is therefore a matter of some regret that the fruits of his labours apparently remain largely clutched to the breast of the author. On the whole it does not cover technical aspects in much detail however.

(Prior to this Clark wrote up the results of an earlier study, also unpublished as far as I am aware:
"Robert Hope-Jones MIEE: An introduction to his contribution to British organ building", dissertation for M Mus in Performance Studies, Reading, 1989).

39. "Robert Hope-Jones", David H Fox, Organ Historical Society (USA), 1992.

Easy to obtain direct from the OHS via Internet purchase. Good value and interesting, but bear in mind it contains some inaccuracies.

40. "The Recent Revolution in Organ Building", G L Miller, Francis Press, New York, 1909.

Miller made no attempt to hide his fawning admiration of Hope-Jones in this book, and sycophancy fairly drips from its pages. However some interesting material can nevertheless be obtained from it if one looks beyond this. For example, Miller was a well qualified professional organist with wide experience of Hope-Jones's instruments both in Britain and the USA, and his impressions and descriptions of them, including many photographs and diagrams of excellent quality, have some value today.

41. "The Organs of St John's Church, Birkenhead", R A D Pope, *The Organ*, April 1937.

An interesting article written while St John's church was still standing (now it is demolished), and soon enough after Whiteley's major rebuild of the organ in 1927 to enable some of the original features they found to be recorded before they vanished for ever. It also contains some good photographs of the church, the organ and its mechanism.

42. "The Life and Work of Ernest M Skinner", Dorothy J Holden, Organ Historical Society (USA), 1985.

Skinner's views on the noisy combination action at St George's, Hanover Square were quoted by Fox [39] and attributed to Holden's work.

43. See *http://www.dhub.org/object/163357* (accessed 28 December 2009; unavailable 4 May 2020).

This former website described a dynamotor (motor-generator or rotary converter) made by the Western Electric Company of Chicago and New York for keeping the batteries charged in Central Battery (CB) telephone exchanges in the early twentieth century. Although this was some years after Hope-Jones's early career in telephony in Britain, it was nevertheless representative of telephone engineering practices at that time.

44. Miller [40] included an extract from Matthews [36] in which Skinner was quoted as saying of Hope-Jones:

"Your patience, research and experiment have done more than any one agency to make the modern organ tone what it is. I think your invention of the leathered lip will mean as much to organ tone as the Barker pneumatic lever did to organ action, and will be as far-reaching in effect.

I believe you were the first to recognize the importance of low voltage electric action, and the world owes you its thanks for the round wire contact and inverted magnet.

Since I first became familiar with your work and writings, I have found them full of helpful suggestions".

(Although Miller attributes this to Matthews, I have been unable to find it in the latter's book).

45. "The Contemporary American Organ", William H Barnes, Fischer, New York, 1937.

Skinner's remarks about combination actions are in a footnote to page 238.

46. "The Modern Organ", Ernest M Skinner, Gray, New York, 1917.

47. A fully electric reverser circuit using two standard relays is described on my website. See Figure A1 in:

www.colinpykett.org.uk/the_evolution_of_electric_actions.htm#APPENDIX%201

Appendix 1 – The Hope-Jones organ at St John's, Grange Road, Birkenhead, 1889

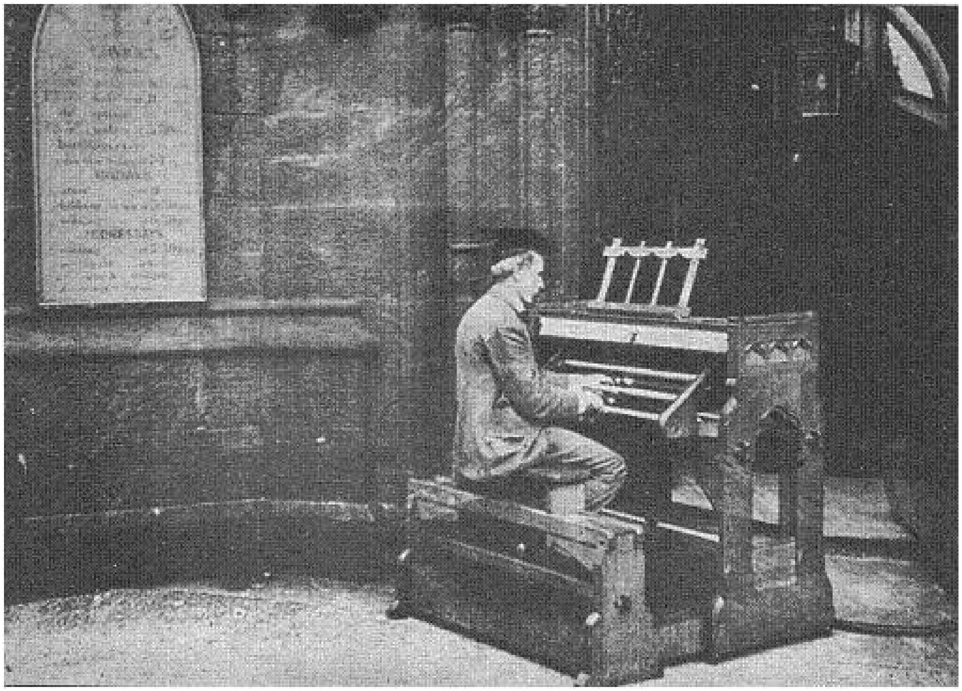
Many details of this organ, important to any historian of Hope-Jones, no longer exist. Apart from the usual uncertainties about its stop list which afflict all lost organs, the several major and many minor rebuilds to which it was subjected, together with the subsequent demolition of the church itself, make it impossible to fill in the many gaps now existing in our knowledge. Therefore I considered it necessary to record here what I have been able to discover or infer about the mechanism of the instrument at the time of writing (2009), insofar as the material affects the subject matter of this article.

Some of the main events in its history were ([5], [41]):

1846	Built by Jackson.
1886-1889	Rebuilt with electropneumatic action by Hope-Jones and Franklin Lloyd.
1894	Rebuilt again – the first of several interventions modifying the action and pipework.
1898	Probable rebuild of some sort according to entries in parish magazines.
1923	A possible further rebuild, though there probably had been others previously.
1927	Completely rebuilt with tubular pneumatic action by Whiteley.
1927	Original electric console and mechanism presumably lost as part of the above.
1970	Unplayable by this date and probably before.
1976	Church demolished.

The material here has been garnered from a variety of sources. Many articles and correspondence appeared in the musical literature during the early 1890's concerning this famous instrument. One article in *Musical Opinion* [21] recorded a visit to the church by a group of organists and part of it was reproduced in Elliston's well known book *Organs and Tuning* [10]. Unfortunately much of this contemporary material is unreliable even when not tainted by deliberate attempts at mischief or smear against Hope-Jones, a common occurrence. This is because most writers of the day were obviously confused by anything electrical as well as by other details of organ mechanism, and this rendered them liable to take too much at face value as often as reporting it incorrectly. Therefore I have tried to make allowances for this by interpreting the material in the context of more reliable information relating to other Hope-Jones organs. I have also applied an independent analysis to some of the data in an attempt to validate it.

It is next to impossible to be entirely sure of many details of the organ. For example, Pope [41] suggested that when first demonstrated c.1890 the organ "was but an incomplete and roughly made working model", though he was only quoting verbatim the words of another author (Reginald Whitworth). The instrument surely could not have been that incomplete and that rough in view of its immediate impact and influence on the world at large as well as on the several thousand visitors who apparently flocked to see it? However one detail he mentioned was that the "suitable bass" system was only "prepared for" in 1890 and remained so at (but also after?) the time of the 1894 rebuild. It should be noted that some of the thumb pistons associated with this system are probably those visible in the photograph of Hope-Jones at the console outside the church door (see below). Pope concluded that after 1894 the history of the organ became indefinite, with Hope-Jones adding or removing experimental stops at various intervals. A fourth manual for a Tuba stop alone was also added at some point, together with new actions and soundboards at various times. Therefore there seems little doubt that it remained a test bed for its creator. Despite all this, apparently the organist in 1896 (B S Lee) was impressed. He wrote to Pope saying, *inter alia*, that Hope-Jones "was a wonder, but in advance of his times".



Robert Hope-Jones playing his celebrated organ at St John's, Birkenhead from outside the church c. 1890. The organ probably reached its first complete form by 1889 having been transformed by Hope-Jones and Franklin Lloyd over several years, assisted by various members of the choir and some colleagues from the telephone company. It was subsequently modified both mechanically and tonally several times. Much of the initial work was done in the evenings in nearby rented premises. Note the cable snaking its way into the gloom within. No pneumatic assistance could have been used to operate any of the mechanism in this console, in particular the coupling and combination actions. This fact plays a key role in the arguments developed in this article. The reason why he chose to wear a mortar board, and which institution had granted it to him, are questions for which I do not have the answers. Some of the wording on the notice board is readable, confirming that this version of the photograph has been printed the correct way round - some others are a mirror image.

Stop List

PEDAL		**GREAT**		**SWELL**		**CHOIR**	
30 notes		56 notes		56 notes		56 notes	
Great Quint	10 2/3	Contra Gamba	16	Vox Angelica	8	Gamba	8
Open Diapason	16	Open Diap Large	8	Bourdon	16	Dulciana	8
Bourdon	16	Open Diap Small	8	Open Diapason	8	Lieblich Gedacht	8
Violone	16	Clarabel	8	Stop Diapason	8	Harmonic Flute	4
Principal	8	Dulciana	8	Salicional	8	Corno di Bassetto	8
Ophicleide	16	Principal	4	Principal	4		
		Flute	4	Piccolo	2	Super Octave	4
Choir	8	Twelfth	2 2/3	Mixture	3 rks	Swell Sub	16
Great	8	Fifteenth	2	Oboe & Bassoon	8	Swell Unison	8
Swell	8	Mixture	3 rks	Cornopean	8	Swell Super	4
Swell Super	4	Tuba Mirabilis	8	Clarion	4	Swell Quint	10 2/3
Swell Quint	10 2/3	Harmonic Clarion	4				
				Sub Octave	16		
		Super Octave	4	Super Octave	4		
		Choir	8	Swell Shutters			
		Swell Sub	16				
		Swell Unison	8	Tremulant (?)			
		Swell Super	4				
		Swell Quint	10 2/3				

- Key action: electropneumatic to bar and slider chests.

- Stop action: electropneumatic (probably double-acting).

- Coupler action: see below.

- Combination action: probably electromagnetic (not electropneumatic) action to the stop tablet action magnets using composition pedals with fixed (non-adjustable) combinations. Thumb pistons may have been added later. "Suitable Bass" and "Independent Pedals" thumb pistons to each manual. The system may have been incomplete when the organ was first demonstrated.

- Swell shutter action: probably electropneumatic using an analogue servomechanism which only required a single wire in the interconnecting cable. The method of operation of this system has been described in the section dealing with swell shutter actions. A further wire may have been necessary so that the "swell shutters" stop tablet and one of the sforzando pedals could have thrown open all the shutters simultaneously.

The stops were controlled by vertical tilting tablets, called "stop keys" by Hope-Jones at the time, probably magnetically motorised to respond to the combination pistons and with mechanical toggle springs to provide a positive tactile action. They were arranged to switch the stop on when touched at the upper end and off when touched at the lower (the reverse of today's convention). Each name was engraved twice, once in full using a small font and again with an abbreviated name using a larger one. Each tablet was said to bear a "coloured button" – white for flue stops, red for reeds and black for couplers - though the buttons may have been mounted on the stop rail above the tablets themselves as they were in later Hope-Jones consoles. Wherever they were placed, the buttons were simply buttons, not telephone switchboard type lamps as assumed by some authors. Ergonomic innovations such as these pre-dated theatre organ custom by many years.

Note the large number of couplers (18), including the curious sub-quint swell coupler to all departments except its own.

The swell shutters were thrown open by means of the "swell shutters" tablet (engraved in green lettering), and also by one of the sforzando pedals.

Blowing was by an Otto town gas engine (variously described as rated between 1 and 2.5 HP in the literature). Two wind pressures were employed – one from a cast iron (piston?) compressor giving 250mm wg to the Tuba, Clarion and Ophicleide, and conventional feeders giving 75mm wg to the rest of the pipework. The engine also drove a DC dynamo giving an action voltage probably between about 4.5 and 8 volts. As with the HP rating of the engine, this figure also varies in the literature. The engine speed was varied electrically and automatically depending on the wind demand.

Accessories

- Stop Switch (bistable button - push-on/push-off - placed between the great and swell stop banks, though it may have been a stop tablet). It was probably duplicated by a pedal.

- 4 combination pedals (later, thumb pistons also?) to swell (fixed combinations).

- 6 combination pedals (later, thumb pistons also?) to great (fixed combinations).

- 4 combination pedals (later, thumb pistons also?) to choir (fixed combinations).

- "Suitable Bass" and "Independent Pedals" thumb pistons to each manual (possibly "prepared for" at first).

- Transposing switch into any key (thus 12 positions), possibly lever-operated in a small box placed to the right of the keyboards which can just be discerned in the photograph above.

- Sforzando pedal for heavy reeds (Tuba, Clarion and Ophicleide on 250mm pressure).

- Sforzando pedal for full swell coupled to great and choir, also opening the swell shutters.

Interconnecting Cable

The flexible cable between the console and organ will be discussed in some detail because it leads to some interesting engineering implications which are explored here. It was about 45m long by 50mm diameter, and was said to have had 343 cores [21]. A minimum wire diameter around 0.5mm (26 SWG) would have been necessary to avoid excessive voltage drop to the action magnets. Nor could it have been much greater, otherwise the cable would have been too fat and inflexible. On the basis of evidence from other Hope-Jones organs the cable also probably had a central common feed conductor about 5mm in diameter consisting of many fine strands. A similar-sized common return conductor for the tablet action magnets would also have been required. All conductors were probably white cotton covered and the whole cable was wrapped in a woven fabric sheath. The cable was terminated within the organ on Hope-Jones's "test board" [21] from which smaller harnesses were led off as required.

Coupler System

If there were indeed 343 cores in the cable, a remarkably precise figure which may well have come from the builder himself, this enables some important deductions to be made about the key and coupler action of the instrument. Each key had to control multiple circuits, one for the associated chest magnet plus one each for the couplers. Because diodes had not been invented, considerations of binary circuit logic dictate that each circuit would have required its own key contact. Thus 7 contacts per key would have been required across most of the compass for the great organ for example. These considerations are discussed at length in the section of the article dealing with Hope-Jones's coupler actions.

If each contact had required a dedicated wire in the cable the great organ alone would have accounted for about 351 wires (taking into account the incomplete compasses of the non-unison couplers), therefore this option can be discounted. Assuming the actual figure to have been 343, the implication is that the coupler switches and their myriad interconnections with the key contacts must have been contained within the console rather than within the organ at the far end of the cable. However electropneumatic switches of the type which was definitely used in other Hope-Jones organs could not have been used here for several reasons. The most obvious one is that no wind would have been available in the console, which was mobile and on the end of a long cable. Moreover it is doubtful whether there would have been room for the necessary number (18) of such large coupler relays inside the Birkenhead console because it was one of Hope-Jones's small "skeleton" designs as can be seen from the photograph above.

So how was the coupling done? At this remove in time and considering that the console was broken up over 80 years ago a definite answer to this question now seems elusive. However a clue exists in that there are occasional references in the literature to the use by Hope-Jones of a combined key contact and coupler switching system in some of his organs (see, for example, [31]), and more details can be found in [34]. Although the latter does not mention the Birkenhead organ specifically, it is reasonable to infer that the system described (or a variant of it) was used to implement coupling in that instrument and probably in others with mobile consoles.

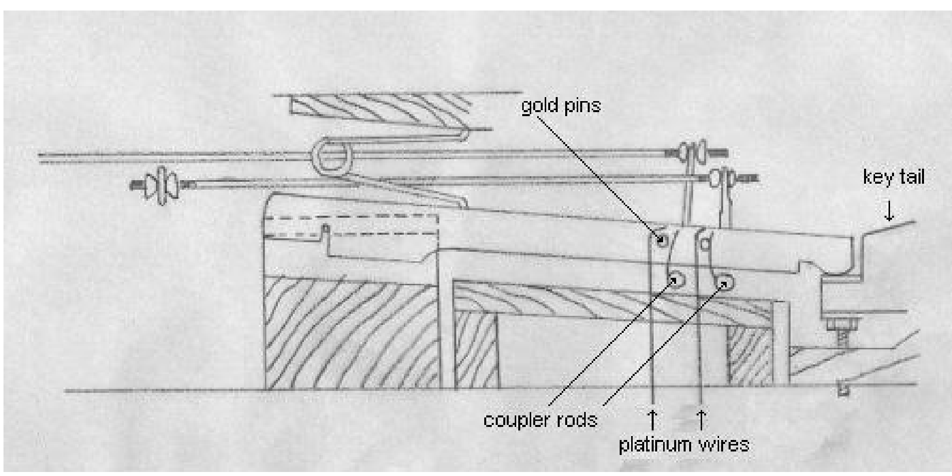


Figure A1-1. Hope-Jones's combined keying and coupling system
(Copyright © Colin Pykett)

As with many of Hope-Jones's diagrams, that which appears in [34] is almost impenetrable as far as the electrical details are concerned. However the essentials of it have been redrawn here in Figure A1-1 with the help of the text which accompanied it. Two couplers are shown, each of which has a metal rod running the length of the keyboard behind the key tails. The rods can be rotated by means of the crank mechanisms shown, and presumably these were operated using small electromagnets although a direct mechanical linkage to the stop tablets might have been feasible. Each rod had a number of platinum contact springs equal in number to the number of keys, and when the corresponding coupler was in the "on" position these bore on gold pins inserted in actuators behind the key tails. When the coupler was off contact between the pins and the springs was removed. Thus in the diagram, the left hand coupler rod is off and the right hand one is on.

The power source is permanently applied to all rods, thus when the key is pressed a voltage appears at the platinum key contacts at the bottom of the diagram for all couplers which are on. The relative dimensions of the original diagram, which have been preserved in this drawing, suggest that several more couplers could have been included for this particular keyboard. An additional contact, not shown but permanently supplied with power in the usual way (i.e. not via a rotating rod), would also have been required for the chest magnet corresponding to this department.

The general concept just described remained more popular in America in the 20th century than it did in Britain, perhaps suggesting that Hope-Jones took the idea with him when he emigrated. It may also have gained acceptance through visits of American organ builders to see Hope-Jones's work in Britain, and E M Skinner was one such who was apparently impressed by his mechanisms if not by his tonal ideas. Indeed, the two of them worked together for a time shortly after Hope-Jones moved to the USA. The technique remained so fashionable in America that it was even used in electronic organs until well into the second half of the 20th century, and a drawing of the combined keying and coupling system used by Gulbransen in the 1960's is shown in Figure A1-2. A similar method was also used by Conn around the same time in their smaller instruments, although their rods were rotated mechanically rather than by using electromagnets.

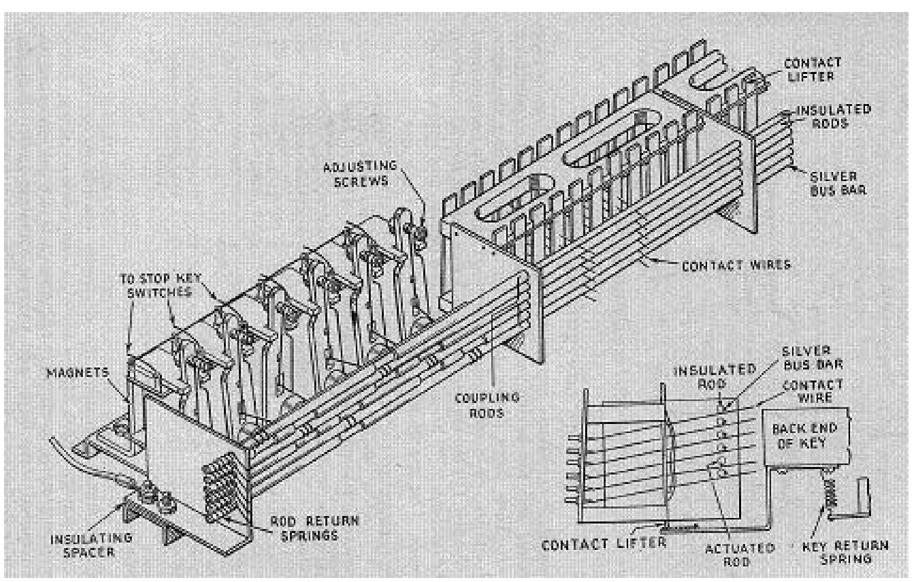


Figure A1-2. Gulbransen combined keying and coupling system c. 1960

The diagram shows six contacts to each key, each of which can be connected to the common supply when the corresponding busbar has been rotated into the correct position by its electromagnet which is controlled by a coupler stop key. When used in a pipe organ an additional key contact, not shown, would also be required to operate the chest magnet of the department concerned. Such an assembly would then correspond to the great department of the Birkenhead organ with its six couplers. It is certain that we see here more than a lingering echo of Hope-Jones's coupler switch ideas because the rotating actuators are similar to those used in his own system as in Figure A1-1, and moreover the two systems are electrically identical. Both implementations fit compactly behind each keyboard, and a further advantage is the major reduction in wiring which is obtained by combining the key contacts with those of the coupler relays.

An alternative method of coupling would have involved the use of keying relays at the organ end of the cable, one for each key. In this case the keys would merely control their corresponding relays which would have the necessary multiple contacts. One cannot dismiss this suggestion entirely because some later Hope-Jones organs used remote keying relays to derive stops placed on unit chests. Theatre organs subsequently used this technique widely, with Wurlitzer employing small electropneumatic relays and Compton using electromagnetic ones in both their pipe organs and some of the Electrones. Both builders relied heavily on Hope-Jones's ideas for their enabling technology. However it would have been an expensive way to do the job at Birkenhead, and moreover there is no mention of it in contemporary accounts. For example, reference [21] describes the astonishment of some visitors to St John's when they entered the organ chamber:

"Within the organ there is no mechanism to be seen. It appears at first sight to consist solely of the bellows, soundboards, and pipes. The spaces usually left in such instruments for the mechanism are in this case utilized for vestries, &c. Insulated wires are led in small cables from the organ test boards on to the other side of each soundboard, where are situated the electro-pneumatic levers which open the air valves below the pipes."

If there had been the requisite 198 keying relays in the organ (one for each manual and pedal key) together with an array of 18 electropneumatic coupler relays, all reposing impressively within their glass fronted cabinets and interconnected with fat wiring harnesses, they would surely have been obvious for all to see and would have been remarked upon in the account above. As it is, the cable arriving from the console simply appeared to be terminated at Hope-Jones's "test board", the term he used in his writings for the convenient tag or pin panel at which he collected the inputs for all the action magnets before distributing them to the various soundboards. This is compatible with an electrical system in which all the key and coupler switching had already been done within the console.

Nevertheless, one still cannot be quite sure. Pope [41] said that coupling was done using electropneumatic relays at the time Whiteley rebuilt the organ with tubular pneumatic action in 1927, and he included a photograph in his article of what seemed to be the relay frame. However the organ had been subjected to an indefinite number of changes by that time, so it is impossible to say whether the coupling system had been one of them. It remains a fact, nevertheless, that if the console was still detached and readily moveable by that date then it would not have been practical to have provided wind to it. Therefore the electropneumatic coupler switches, if employed, would have had to be inside the organ itself, and consequently keying relays would also have been necessary for the reasons just outlined. Whether this system was employed at the outset in 1890 is impossible to say.

Cable interconnection budget

No wires were needed in the cable for the combination pistons or the tablet action magnets because these would have been interconnected directly within the console.

Each speaking stop tablet probably needed two wires because of the double-acting slider actions, and in fact single pole double throw stop switch circuits were described by Hope-Jones in his patents.

With these assumptions in addition to those above we can arrive at a plausible interconnection budget for this organ as follows:

Item		Wires	Remarks
Keys:	Pedals	30	1 wire per key: output from coupler system (see above).
	Great	56	Ditto.
	Swell	56	Ditto.
	Choir	56	Ditto.
Speaking stops (34):		68	2 wires each.
Couplers (18):		0	Coupling done in console (see above).
Transposer:		12	Guess.
“Swell Shutters” tab:		1	Connected to “OPEN” magnet in swell action (Fig. 31).
Sforzando pedals (2):		0	Connected within console.
Swell pedal:		1	See Fig. 31 for probable circuit.
Combination pistons:		0	Connected within console.
Tablet action magnets		0	Ditto.
Stop switch:		0	Ditto.
Tremulant:		1	If present.
Total:		**281**	**Estimate.**

This leaves 62 unused wires in the 343-core cable, which adds to the plausibility of the scheme because no sensible engineer or organ builder would fail to accommodate a fair number of spare conductors in case of breakages or to accommodate subsequent changes.

Appendix 2 – Detailed analysis of a Hope-Jones organ action when powered by dry cells

A simple analysis of an organ powered by dry cells was given in reference [9]. However it did not take into account the internal resistance of the cells or circuit resistance, the fact that the magnets will not operate below a minimum voltage, "battery fatigue" and the long term fall in open circuit voltage as a dry cell discharges. All these factors are included in the more realistic analysis here. Only the results of the analysis are included rather than the mathematical details required to derive them.

Note that the essential assumption is made here that the organ has an electropneumatic combination action rather than an electromagnetic one. This is because dry cells of any type could not have provided sufficient peak power in the latter case when the pistons were used.

The following parameters are defined:

N = number of magnets energised simultaneously
R = resistance of each magnet
V = open circuit action voltage, assumed supplied by a battery of dry cells
Ri = internal resistance of the battery plus circuit resistance
r = load resistance due to one or more magnets
Vmin = minimum voltage required to work each magnet

1. Number of magnets which can be operated simultaneously

The number of magnets which can be operated simultaneously in a given organ is limited by the internal resistance of the battery plus the circuit resistance. As more magnets are added (e.g. by playing more notes) eventually the voltage across each magnet will fall below the minimum voltage required for the magnets to operate.

Let:

V = 6 volts (4 dry cells in series), the most probable voltage used by Hope-Jones
Vmin = 2.5 volts (reference [18])
R = 50Ω
Ri = 1Ω

Then it can be shown using Ohm's Law that N = 70.

Thus up to 70 magnets could be energised at once. This number might seem comfortably adequate but in a large Hope-Jones organ it could have been easily exceeded. For example, consider the case where an 8 note chord was played on four coupled manuals using a super octave coupler on each. The notes played are assumed to be such that they do not create missing notes due to the octave coupling i.e. 16 chest magnets per department are energised. The conservative assumption is made that no magnets are energised for the speaking stop and coupler actions because of the automatic power cutoff measures used in some of Hope-Jones's organs (i.e. these magnets are automatically switched off after they have performed their function of moving the sliders or operating the coupler relays).

The number of chest magnets energised is 64, which is uncomfortably close to the 70 magnet limit because no allowance has been made for pedal notes, coupling to the pedals, sub octave couplers or magnets performing other functions. In particular, the combination pistons could not be used at all while holding this chord.

Now let the internal resistance of the battery plus circuit resistance (Ri) rise to 2Ω. This could occur either because the internal resistance of dry cells rises rapidly owing to "battery fatigue" as they are used because of hydrogen production in the cells which cannot be neutralised quickly enough. Or it could occur because the internal resistance is higher in older cells in any case. In practice a combination of both factors would be likely.

In this case N reduces to 35, half of the previous value.

This would seriously limit the number of notes and couplers which could be used in any Hope-Jones organ. Even without any notes played or couplers drawn, the combination pistons could not be used if more than 35 stop tablets were involved. This could occur in quite small organs by Hope-Jones if the "suitable bass" and "coupler" options of a compound composition key were both invoked.

Because of the significant current drawn, cell fatigue due to hydrogen production would set in rapidly, typically over a minute or two. Therefore even if the battery was capable of operating 70 magnets initially, it would soon cease to do so because with 70 magnets the current required would be 3.5 A. This would be an excessive drain on any dry battery both then and today. It explains why battery operated organs would often not make it through to the last verse of a hymn in those days.

In both the above cases note that V = 6 volts, implying that the use of fresh cells was assumed which had an open circuit voltage of 1.5 volts each. In practice the open circuit voltage of a dry cell decreases with age, thereby further reducing the value of N.

2. Stored energy considerations

We have noted already that the voltage of a dry cell will fall with time as current is drawn due to two factors – there is a short term fatigue problem (which increases the internal resistance) superimposed on a longer term fall in open circuit terminal voltage as the battery ages. The organ action will continue to work until the limiting threshold voltage of the magnet (Vmin) is reached. It is useful to be able to relate this to the required stored charge rating in ampère-hours (Ah) of each cell of the battery. This is seldom quoted explicitly for dry cells, both for commercial secrecy and because of the number of variables on which it depends. (Try to find the scientific basis for today's dry cell claims such as "no other battery lasts like this one" and you will see what I mean). Therefore we have to work quite hard to get at the necessary data.

The capacity of a cell in Ah is the area enclosed by the current-time curve as the cell discharges under the desired operating regime e.g. constant load, constant current, etc. The blue curve in Figure A2-1 is a typical plot of how the cell voltage falls over time under constant load and it is more relevant to the organ application than the constant current case. Measurements below 0.8 volts are usually not given by dry cell manufacturers which is why the voltage axis does not go below this value. The red line is a straight line approximation to the blue curve which was used to simplify the analysis here. In this work the Ah figure for the cell was taken as the area enclosed by a linear (red line) current-time curve when the voltage has fallen to 0.8 volts under constant load.

Figure A2-1. Dry cells: approximate generic discharge characteristic under constant load

In reference [9] the analysis assumed that the total time for which the organ was actually played is given by taking 10 hymns per Sunday of 2.5 minutes duration each, and doubling this to account for psalms, canticles, voluntaries, etc. This equates to a miserly usage figure of 50 minutes per week. Then, taking a period of 6 months or 26 weeks, a total playing time of 1300 minutes or 21.7 hours would result.

The article [9] also assumed 11 magnets were energised (a 4 note chord played on two coupled manuals plus a pedal note also coupled to both manuals). However the three implied coupler relay magnets were ignored. In [9] values for V (supply voltage) and R (magnet resistance) were taken as 12 volts and 100 ohms respectively. Here we shall use 6 volts and 50 ohms for compatibility with the previous analysis in section 1 of this Appendix. However it makes no difference to the current consumed per magnet and hence to the required storage capacity of each cell in the battery.

Using these figures again here, the required storage capacity of each cell turns out to be about 23 Ah, taking into account battery internal resistance plus circuit resistance (1 Ω), minimum magnet operating voltage (2.5 V) and a linear cell voltage reduction over time (the red line in Figure A2-1). This contrasts with the figure of 26 Ah derived in [9] in the simpler situation where internal resistance and circuit resistance were ignored, there was no minimum magnet operating voltage and the battery voltage remained constant over time. Because the difference is not great it is therefore more important, as in [9], to emphasise that the figure would need to be multiplied by a significant factor before it could be considered realistic. This is because the time for which the organ was actually being played in both cases was assumed to be only a trifling 50 minutes per week, a most unlikely figure.

Multiplying the storage figure by 3 or 4 therefore gives a more realistic value of 75 – 100 Ah per dry cell before one could conceive of using them to power even a small organ for a period of 6 months.

Appendix 3 - Light Relief!

If you have found the foregoing somewhat indigestible, here is something completely different. It is a representative assortment drawn from the less enthusiastic writings about Hope-Jones during the last half-century or so by some personalities well-known in the British organ world. The entries are listed alphabetically by author. Factual inaccuracies have not been permitted to stand without remark.

oooOOooo

To set the perspective .....

After your death you were better have a bad epitaph than their ill report while you live.
William Shakespeare [2]

What is written without effort is in general read without pleasure.
Dr Johnson [3]

Every great and original writer, in proportion as he is great and original, must himself create the taste by which he is to be relished.
William Wordsworth [4]

So strong are the feelings aroused by the mention of his name that extreme care has to be taken in assessing his work. ... Given that Hope-Jones was admired by large numbers of otherwise sensible and well-educated musicians, that he was successful in landing a large number of contracts for new organs, and that his work was profoundly influential both in Britain and America, these highly subjective statements clearly need to be treated with some circumspection.
Stephen Bicknell [5]

oooOOooo

Colin Beswick; Precentor and Sacrist of Worcester:

- "*[Hope-Jones's Worcester Cathedral]* instrument must have been thoroughly unmusical and proved equally unreliable" [6]
- *[It had]* "fearsome tonalities" [7]

Relf Clark; solicitor, performer and musicologist:

- "Was it *[the withdrawal of financial support by a local benefactor to Worcester Cathedral]* connected in some way with a famous criminal trial that took place in May 1895, and the reason for Hope-Jones's sudden emigration to America, in April or May 1903?" [8]

[2] Hamlet
[3] *Life of Johnson*, Boswell
[4] Letter to Lady Beaumont
[5] *The History of the English Organ*, Cambridge, 1996
[6] *The Organs of Worcester Cathedral*, Worcester, 1967
[7] *ibid.*
[8] *An apparently controversial instrument*, JBIOS (17), 1993

- " ... it *[a photograph of Hope-Jones]* caused me to wonder ... whether 'eccentric', the adjective so often applied to H-J, was not a euphemism for 'mad' " [9]

Cecil Clutton; real estate agent and dilettante writer on clocks, classic cars and organs:

- " ... it took British organ-building 55 years to sink from William Hill's masterpiece at the George Street Chapel in Liverpool to the banality of Hope-Jones at Worcester Cathedral ... " [10]

- "Whatever merits the thing *[Hope-Jones's Worcester Cathedral organ]* might have been considered to possess, the fact remained that it was incapable of playing any music ever written for the organ *{manifestly false}*, and no one ever wrote any music for it. The only exception is Elgar's organ sonata which is perhaps hardly a sufficient excuse by itself" [11] *{also false – this work was premièred in 1895, the year before Hope-Jones's organ was completed}*.

- "Finally, as a sort of *fin-de-siècle éminence grise*, came Robert Hope-Jones; an electrical engineer by trade who unfortunately strayed into organ building, to which he applied an electric action of more ingenuity than reliability and then a tonal system of tasteless vulgarity" [12]

- "In 1903 he removed to America, where he had such considerable success that it took 40 years for American organ building to recover from him" [13]

Donald Hunt; Worcester Cathedral organist:

- *[Hope-Jones's Worcester organ]* "was a non-starter and, mostly due to a collapse of the "home-made" action, it took very little time to become hopelessly unplayable" [14] *{the organ was inaugurated in 1896 and was not rebuilt until 1925, 29 years later}*.

Christopher Kent; university lecturer (Reading):

- *[Hope-Jones was]* "by trade a telephone engineer, who strayed into the craft of organ building" [15]

- "He initiated some of the most bizarre and grotesque sonorities that have ever emerged from an organ" [16]

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[9] JBIOS (26), 2002, p.192
[10] *The British Organ*, London, 1963
[11] *ibid.*
[12] *ibid.*
[13] *ibid.*
[14] *The Music and Organs of Worcester Cathedral*, B Still, D Hunt & P Wood, Worcester, 1978
[15] *Elgar's Organ Sonata in G (Op 28) ...* , JBIOS (2), 1978

Michael Sayer; university lecturer (Keele):

- " ... analysis of his work in the absence of technical records has inevitably been subjective, alternating between eulogistic praise of his technical innovations and scathing contempt for his musical bad taste" [17]

- *[Hope-Jones]* "spoke as an engineer in engineering terms of technical problem-solving through mechanisms evaluated on criteria of cheapness and short-term efficiency" [18] *{evidence for this assertion was not provided}.*

- *[He]* "was no more than a technician-engineer with no appreciation of ... artistic organ design ..." [19]

- " ... the Hope-Jones organ inspired no serious musical compositions" [20]

- "Hope-Jones' weakness as a maker of musical instruments is revealed in his remark (quoted ... in the RCO lecture) *{sic – the College was not 'Royal' at that time, 1891}* about tones "obtained in a most beautiful and scientific manner", a comment fairly typical of the post-industrial uncultured engineer who equates "beautiful" with the rational and ordered nature of scientific laws, but whose scientific knowledge excludes the apparently irrational nature of many physical laws ... for example ... simple current theory in semiconductors" [21] *{Hope-Jones died in 1914, years before quantum theory matured in the late 1920's. Only then did the behaviour of semiconductors begin to be understood, culminating in the invention of the transistor in 1947. Therefore he could not possibly have had any notion of semiconductor theory. Even the word as Sayer used it did not appear until the 1930's; in Hope-Jones's day it meant something quite different}.*

- "The engineer with so restricted a view of science was also liable to have a more restricted concept of artistic values ... " [22]

- " ... Hope-Jones and his followers were making a commercial business of ostensibly solving ... problems whilst actually imposing an uncultured vulgarity on an art that had lost direction" [23]

- "Hope-Jones *[sic]* survivals are now scarce, mainly because of the short life of electric mechanisms *{no evidence was provided for this generalisation}* and the appallingly uncultured taste of their maker ... " [24]

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[16] *ibid.*
[17] *New Light on Hope-Jones*, The Organ, 1981
[18] *ibid.*
[19] *ibid.*
[20] *ibid.*
[21] *ibid.*
[22] *ibid.*
[23] *ibid.*
[24] *ibid.*

Peter Williams; musicologist:

- *[Hope-Jones built]* “the worst organs ever made by a careful, professional builder” [25]

- *[They]* “are considered the worst in organ design” [26]

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[25] *A New History of the Organ*, London, 1980
[26] *The Organ*, London, 1988

About the Author

Colin Pykett has a first class honours degree and a PhD in physics from King's College London, and he is also a Fellow of the Institute of Physics. He became Chief Scientist and Technical Director in a high-technology organisation following a career during which he spent many years working in acoustics and digital signal processing.

His musical training began with the piano at the age of six, and subsequently it took in the oboe and the organ. Initially he studied the latter instrument with the late Russell Missin at St Mary's, Nottingham, and subsequently he received tuition from others of similar stature while at university. He has played the organ in many churches over nearly fifty years.

Colin has undertaken research in organ topics for several decades, particularly in the mechanisms of sound generation in organ pipes. He is recognised internationally for his work on electronic tone production, having published his first papers on the subject in 1980. More recently he has investigated responsive mechanical and electric actions for pipe organs from both an experimental and a theoretical standpoint.

His interest in Hope-Jones is motivated partly because there is a widespread of lack of knowledge at a detailed level about how his organs worked, hence this article.

Colin maintains a website at *www.colinpykett.org.uk*.

The author at the Hope-Jones museum of the Lancastrian Theatre Organ Trust in Manchester, England, flanked by the late Don Hyde (left) and Roger Fisher. They are sitting on one of Hope-Jones's distinctive organ benches with its raised centre portion.

In the background are the consoles from the Hope-Jones organs at St Paul's and St Modwen's, Burton upon Trent discussed in this article, whose dusty innards had just been explored. Some Hope-Jones pipework can also be seen.