Hydrodynamic Bearings - Robust Design Ensures Success
Paliers Hydrodynamiques – Une Conception Robuste est la Garantie du Succès

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When Michell and Kingsbury successfully applied their solution to Reynold's equation, the tilting pad bearing came into existence. The design was simple and elegant and offered significant performance advantages to users. Whitemetal (Babbitt), a material conceived in the 19th Century, was utilised as a sacrificial lining.

Today, more than 100 years on, the same fundamental concept appears to be going strong. Over the years, robust designs have prevailed and designers have enhanced their products and improved performance. Materials have also improved and alternative linings to whitemetal have emerged. Fluid film bearings are well established across a huge variety of applications, many with demanding operating and environmental conditions.

The authors look at some of the successful designs that have become commonplace, how designs have progressed and how lining materials have evolved. Finally, some recent bearing developments are reported and conclusions are drawn about the requirements of plain bearings in the future.

Quand Michell et Kingsbury ont réussi à appliquer avec succès leur solution à l'équation de Reynold, le palier à patins pivotants a vu le jour. La conception en était simple et élégante et offrait aux utilisateurs des avantages significatifs en termes de performances. Le métal blanc (ou Babbitt), un matériau conçu au XIXe siècle était utilisé comme revêtement sacrificiel.

De nos jours, plus de 100 ans après, le même concept fondamental n'a rien perdu de sa valeur. Au fil des années, les conceptions robustes ont prévalu et les concepteurs ont apporté des améliorations à leurs produits et à leurs performances. Les matériaux ont également été améliorés et d'autres revêtements que le métal blanc ont fait leur apparition. Les paliers à film fluide sont aujourd'hui bien établis dans une très grande variété d'applications, dont beaucoup dans des environnements et des conditions de fonctionnement particulièrement contraignants.

Les auteurs examinent quelques unes des conceptions les plus performantes devenues usuelles, comment les conceptions ont progressé et les matériaux de revêtement évolué. Enfin certains développements récents de paliers sont évoqués et des conclusions sont tirées quant aux exigences futures des paliers lisses.

1 Introduction

Albert Kingsbury and Anthony George Malden Michell are each credited independently with the invention of the tilting pad bearing. Kingsbury's US patent was granted in 1910 [1] whilst Michell's thrust bearing patent [2] was granted in 1905 and his journal bearing patent [3] in 1912. The Michell patents describe the idea of a series of segmented bearing 'blocks' each pivoted on the back so that "the film of oil between each block and the surface on which it bears may be more compressed or constricted at the rear end than at the front or leading end of the block, a condition which favours the entry of the oil between the surfaces at the leading end." Figure 1 shows an illustration from Michell's 1905 patent.

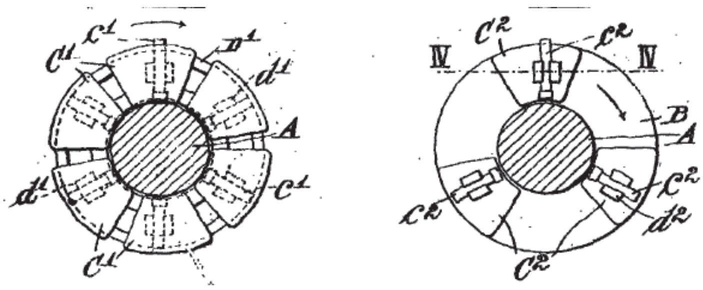
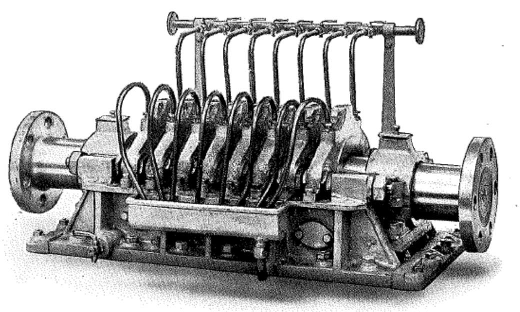


Fig. 1 – An Illustration from Michell's Patent No 875 Granted in 1905

It is not until one compares the tilting pad bearing to the technology of the time that one appreciates the significance of the invention. Prior to the tilting pad invention, bearings were characterised by unreliability and unpredictable lifespans. A very clear example of this is thrust blocks which absorb the thrust from the propeller of ocean going vessels. In the 19th century marine thrust block designs utilised multi-collar technology and, for at least one merchant liner, 22 collars were required to transmit the thrust onto the flat bronze counter-faces [4]. Balancing the load so that each thrust element carried equal load was particularly problematic and continual adjustment was required. In addition, high power losses were inherent with the multi-collar design. Figure 2 shows a photograph of a typical design and illustrates the complexity of the arrangement. In contrast, Figure 3 depicts the equivalent, circa 1916, Michell tilting pad thrust block design for the same duty. The design utilises a single collar thus reducing the complexity and lowering power losses whilst, simultaneously, allowing significantly larger loads to be transmitted. The immediate impression is that the Michell design is much simpler resulting in installation benefits and much lower maintenance requirements. It was estimated that the Royal Navy saved £500,000 GBP worth of coal in 1918 alone as a result of fitting Michell's tilting pad bearings [5].



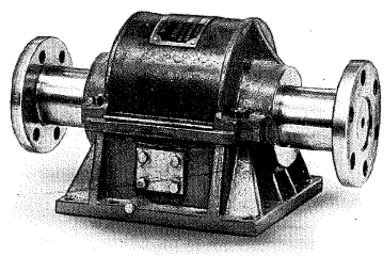


Fig 2 – Multi-Collar Thrust Bearing ***Fig 3 – Equivalent Michell Thrust Block***
source : The Michell Bearing Book, 3rd Edition, first published 1916

In a similar fashion, Kingsbury's bearing fitted to Unit 5 of the Holtwood Hydroelectric Station in 1912 was said to carry 100 times the load taken by the previously fitted roller bearings [6]. During overhaul in 1950 the bearing was reinstalled having been described as in 'perfect condition'. Clearly the tilting pad design resulted in a step change in bearing performance and reliability.

The authors' argument is that robust designs that enjoy longevity are inherently reliable and often have a deceptive simplicity about them. Both Kingsbury and Michell had been able to recognise the significance of the work undertaken by Tower [7] [8] and Reynolds [9] in the 1880's, the stimulus for which was the poor reliability of railway axle bearings. Michell was the first to extend Reynolds' classical work and obtain solutions which took account of side leakage. Tilting pad designs were developed that positioned a pivot point over the centre of fluid pressure thus creating a component that always positioned itself in the optimum position. This concept is still as relevant today as it was back then and, as has been observed [10], bearing designs today still bear great similarity to those of the past. This should not be seen as a negative as surely it is a case of admiration that, despite advances in technology, sound, well thought out designs that are inherently reliable can continue to flourish and satisfy their requirements for a great number of years.

It is a very similar story for the plain bearing lining of choice. Whitemetal (Babbitt) has been in use since its conception in 1839. In the early 19th century dissimilar metals were being used to run against each other. Bronzes were often used as a bearing surface which were followed by the use of tin and lead [11]. However, whilst both tin and lead were excellent at embedding dirt particles and operating in boundary lubrication conditions, neither of these materials had the strength to carry the desired loads. Isaac Babbitt patented an alloy in 1839 whereby copper and antimony were added to tin in order to improve strength and hardness. Thus whitemetal came into existence. Despite the growth in the use of alternative materials in many other industries, whitemetal is still the principal material that is associated with plain bearings today.

This said, plain bearing designs have not stood still. More demanding requirements have pushed designers into finding ways to extend both the operating envelopes and the life of products. Poor designs have fallen by the wayside whilst robust designs have endured. In the next section, the authors look at some successful bearing solutions and bearing features which have stood the test of time.

2 Robust Designs

The passage of time has seen plain bearings becoming progressively more reliable. Whilst there is more than one way to solve a given problem, well designed bearings are sympathetic to the requirements of the application, regardless of their style and should operate successfully without incident, remaining inconspicuous.

In terms of thrust pad designs and thrust pad supports, three types of thrust pad are very commonplace. They are the conventional line pivoted pad (Figure 4), the button/spring plate supported pad (Figure 5) and the spring mattress supported pad (Figure 6).

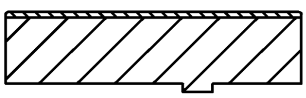


Fig. 4 – Conventional Pivot

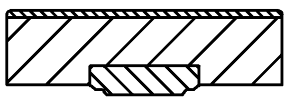


Fig. 5 – Button Support

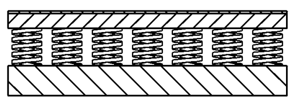


Fig. 6 – Spring Mattress

The type of thrust pad support used is generally dependent upon size, whereby as size increases the pad support mechanism becomes more sophisticated. The vast majority of thrust pad applications can be satisfied using conventional pivots and button supports, however, as the size of the thrust pad increases, the challenge for the designer is to control the amount of thermal and mechanical distortion otherwise failures can occur both during transient conditions [12] and steady-state performance. For large bearing designs, such as those employed in hydroelectric applications the radial width of thrust pads can exceed 900 mm. The spring mattress design, introduced in the 1940's [13], is particularly versatile and is capable of operating successfully in this size range. In 1997 it was reported [14] that General Electric had over 800 bearings of this type in operation in hydroelectric applications. Other choices of thrust pad support systems are available and, over the years, machine manufacturers, rather than bearing specialists, have developed their own in-house techniques of providing bearing solutions. In addition to the spring mattress designs, elastomer support designs, membrane support designs and double layer designs (Figure 7) are also used successfully.

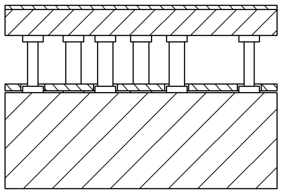


Fig. 7 – Double Layer Thrust Pad Design

It is also worthy of note that, whilst sector shaped thrust pads are the most prevalent and versatile design type, circular shaped thrust pads have been successfully operated in a number of applications since their conception in 1968 [15]. This type of thrust pad must therefore also be considered to be a robust design.

When it comes to radial bearings, plain cylindrical bushes are undoubtedly the most utilised. Despite being the oldest and simplest design, the plain cylindrical bush is remarkably versatile in terms of its operating envelope, its size range and its ability to satisfy requirements across a wide range of applications. Even though the operation of the plain bush was not understood until the 1880's, they had been employed in their whitemetal lined form since 1839 (when Babbitt invented the alloy). When the tilting journal pad design emerged in 1912 the plain bush was not superseded but rather tilting pads designs found their place in environments whereby they could satisfy more onerous operational requirements.

Whatever the application, whether horizontal or vertical, tilting pad or journal bush, all bearings must be furnished with lubricant in sufficient quantity that satisfies the bearing duty requirements. Oil circulation can be achieved by means of external pumps and, in cases where shear losses are high this may be the only option, but the simplest concept is to use the motion of the rotating shaft to circulate the lubricant. This method is tried and tested and has proven extremely robust in a number of guises. Figures 8 and 9 show two methods employed in horizontal bearings using pick-up rings to circulate the oil to the working surfaces. In each case the working bearing surfaces are above the standing oil level at start up and so the rings must deliver oil with haste within the first few revolutions of the shaft. Both methods are in very common use today but have been used for over a hundred years. In fact it is reported that loose ring bearings were exhibited in London as early as 1848 [16]. Whist both designs have the different core strengths their robustness cannot be denied.