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Michell and the development of tilting pad bearings

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The major contribution of A.G.M. Michell to the science of lubrication through his three dimensional solution to Reynolds' equation is well-known. Much less known is the story of the industrial introduction of tilting pad bearings to Europe and the eventual establishment of a specialist bearing company carrying the inventor's name. The purpose of this paper is to relate something of this history and then to highlight some of the subsequent technological changes encountered by the company, Michell Bearings, in the 65 years of its existence.

1. INTRODUCTION

The personal biography of A.G.M. Michell, figure 1, has been documented several times (1, 2, 3) and most recently and comprehensively by Dowson (4, 5). On the occasion of the Osborne Reynolds centenary it is perhaps appropriate to recall that Michell (6) in 1905, nineteen years after Reynolds had considered the lubrication of plane surfaces, obtained a three dimensional solution to Reynolds' equation which took account of side leakage. Nearly forty years later, on the occasion of the James Watt International Medal presentation in 1943, Michell's achievement even then was said to be the only really important extension of Reynolds' theory yet effected.

2. FIRST USES OF MICHELL BEARINGS

Michell took out patents covering his tilting pad invention in Australia and Britain in 1905, the same year that his solution to Reynolds equation was published. At the time Michell was running his own small consultancy business specialising in hydraulic machinery. The first tilting pad bearing in service was probably that built under his guidance by George Weymouth (Pty) Ltd., for a centrifugal pump at Cohuna on the Murray River, Victoria in 1907, (5). The bearing, shown in figure 2, was described by G.B. Woodruff (7) in a lecture given to the Institute of Marine Engineers in October 1908. The same bearing was also described later by H.T. Newbigin in "The Michell Bearing Book", a private publication dated April 1916. According to Newbigin the total load was 13.3 kN (3000 lbf), equivalent to a specific bearing load of 1.5 MPa (220 psi) and the running speed was 200 revolutions per minute. When the bearing was stripped down after five months of continuous running hand scraper marks were still evident on the tilting pad surfaces such had been the absence of wear. Evidently the success of the installation was rewarded for Newbigin notes that 'a large number of the bearings have since been fitted to pumps of this kind'.

The early industrial development of Michell bearings took place through the granting of manufacturing licences to interested parties. In England Michell formed a partnership with H.T. Newbigin, who was a fellow civil engineer based in Newcastle-upon-Tyne, to promote his invention and administer the licensing arrangements. The actual date of the formation of the Michell - Newbigin partnership is uncertain. However in the discussion following a paper presented by J.H. Gibson to the Institute of Naval Architects in 1919 (8), Newbigin claimed to have introduced the Michell bearing to Britain in 1905 and it is possible that he and Michell already had some working arrangement as early as this. Certainly Newbigin had co-operated with Woodruff in the preparation for the latter's 1908 lecture which has the distinction of being the first published account in Britain of Michell's invention other than in the 1905 patent application.

In a paper delivered to the Institution of Civil Engineers in February 1914, Newbigin (9) describes a Michell bearing designed by him for Belliss and Morcom in 1910. The bearing which is shown in figure 3 carried a load of 6.7 kN (1500 lbf), corresponding to a pressure of 3.5 MPa (500 psi), and operated at 1750 revolutions per minute. Judging from the discussion, the paper must have raised considerable interest and particular attention was given to the question of the optimum position for the pivot upon which the pads tilt. In the discussion of another paper by Gibson (10), Newbigin gives details of tests carried out on the Belliss and Morcom bearing in June 1910 to determine the effect on pad temperature of different pivot positions while retaining constant operating conditions. Temperature was measured by a thermometer placed in a hole in the pad, close to the working face. At the duty conditions given above the following results were obtained: with the pad pivoted 3 mm (1/8 inch) behind centre, which was close to the optimum point according to the Michell theory, a temperature of 51.1°C (124°F); was recorded; pivoted 1.5 mm (1/16 inch) behind centre the temperature was 52.2°C (126°F); pivoted at the centre, 55.6°C (132°F); pivoted 1.5 mm (1/16 inch) in front of centre, equivalent to an offset pivot operating in reverse, the temperature was 57.2°C (135°F). This early evidence of the considerable reverse running capabilities of offset pads is of contemporary interest for as a recent paper (11) makes clear this is a feature of tilting pad bearing operation which even now is not well documented.

It seems that the adoption of tilting pad bearings for land based machinery proceeded in the next few years steadily if not spectacularly. In his 1914 paper, Newbigin (9) was able to state that considerable numbers of Michell thrust bearings had been made in Australia and England, and by 1916, in Britain alone, upwards of 800 Michell thrust bearings were in service (12). They were in use for a range of applications from high speed steam turbines to low speed, high load grinding machines. In this latter case quoted by Newbigin the lubricant was thick grease and 1½ ounces were required each day.

It is interesting to note even at this early stage the principal bearing designers, Newbigin in England and Michell in Australia, were turning their attention to the problem of maintaining effective lubrication independently of external oil supply. Figure 4, taken from Newbigin's "The Michell Bearing Book" of 1916, shows a vertical self-contained journal bearing which was fitted to two vertical circulating pumps at Newport Power Station in Melbourne, Australia. Circulation of the lubricant is achieved by a fixed curved nozzle projecting into a reservoir rotating with the shaft at 490 rpm. The bearing is formed by the four spherically seated, tilting "bearing splints" shown separately in figure 4. In later years the design of self-contained systems became a major speciality of Michell Bearings which extends to the present day.

3. MARINE THRUST BEARINGS

Up to 1914, the use of tilting pad bearings for the thrust blocks of ships had barely commenced although it was this application which was eventually going to lead to the real boom in interest in Mr. Michell's bearings. The published discussion which followed Woodruff's 1908 lecture gives some idea of the enormous scepticism Newbigin must have faced among marine engineers in the early stages. He persevered trying to interest shipbuilders in the Michell principle but was completely unable to get anyone to abandon the traditional multicollar thrust block with flat horseshoe surfaces. In truth though, Newbigin was not only competing against conservatism in shipbuilding and designers but also contending with a barrier caused by another technological change.

The direct drive steam turbine developed for marine use was being increasingly installed in vessels of the early 1900's. In these turbines practically all the thrust was balanced by steam pressure on a dummy piston (13). A small thrust was indeed necessary on the end of the turbine spindle but its purpose was merely to register and maintain the fore and aft position of the rotor in the casing; its loading was negligible compared with the total thrust of the ship. H.M.S. Repulse, for example, launched on 8 January 1916 and in her day the most powerful warship in the world was fitted with the largest direct drive turbines ever built up to that time. In consequence Repulse, a four screw ship, had no requirement for main thrust blocks but for "only a comparatively small block on each line of shafting", (14). Nevertheless each block had a thrust surface of 2.82m² (4,370 in²) on 16 collars. Since the load was almost nothing it is not surprising that these bearings evidently performed perfectly well.

With the arrival of the direct drive turbine, thrust bearing problems of wear and overheating which had tended to dog earlier ships fitted with reciprocating engines, had apparently gone away. Existing bearing technology was good enough and who wanted to risk a large and costly ship by replacing a large and satisfying multicollar thrust block with what must have seemed a ridiculously small single collar device? The situation might have remained like this for some considerable time were it not for another technological change which re-opened the way for the tilting pad bearing just as effectively as the direct drive turbine had blocked its progress.

In the years from 1912 onwards the geared turbine was developed for marine use and in time superseded completely the direct drive turbine. Now with the turbine driving through a gearbox there was no longer steam available to balance the main thrust and once again shipbuilders were required to fit propulsion shaft thrust bearings capable of supporting major loads. At first standard multicollar blocks were installed with all their attendant difficulties only worse than before. It was suggested that the varying torque from reciprocating engines of the earlier generation had led to fluctuating thrust loads and this had allowed oil to be drawn in between the flat and parallel bearing surfaces. Now however the relentless drive of the turbine driven ships gave no such opportunity and marine engineers began to search urgently for a better means of absorbing thrust. Fortunately for all concerned, the solution in the form of the tilting pad thrust bearing had been in waiting for several years and it was not long before the first installations were made.

Some experimental work was put in hand by C.A. Parsons and Co., in the early part of 1912 with a view to testing the suitability of single collar tilting pad thrusts for marine use. Prior to this Parsons had tried and tested a small block having a bearing surface of 1290 mm² (2 in²) per pad up to a pressure of 24.1 MPa (3,500 psi). The full scale experiments commenced at Wallsend in August 1912 with loads of up to 368 kN (83,000 lbf) being applied to a test bearing at rubbing speeds which ranged between 0.3 to 15 ms^{-1} (1 to 50 fts^{-1}). The maximum load, 368 kN, actually applied was equivalent to a surface pressure of 20.6 MPa (3,000 psi) (8).

Following the success of Parsons' Wallsend test work the first pivoted pad main thrust blocks were commissioned. These were for the first all-geared destroyers, H.M.S. Leonidas and Lucifer, built by Messrs. Palmer of Jarrow and engined by the Parsons Marine Co., and the thrust blocks for the channel steamer Paris, built by Messrs. Denny of Dumbarton. Of these vessels the Paris was first on trial in June and July 1913 (8) with twin thrust blocks taking 239 kN (54,000 lbf) each at about 300 revolutions per minute, (9).

At the time that the Paris was on trial Cammell Laird & Co. Ltd., of Birkenhead were having a great deal of trouble with the standard multi-collar thrust block in a geared turbine cross channel ferry built by themselves. J. Hamilton Gibson, then Chief Mechanical Engineer at Cammell Laird heard of the Paris installation and contacted Newbigin for his assistance. Very quickly a tilting pad design was produced and Gibson persuaded his company to allow him to install Michell bearings in two geared turbine ships then under construction for the Argentine Navigation Company to operate as passenger ferries between Buenos Aires and Montevideo (13). The 107 m (350 ft) long, 5635 shaft horse power vessels were launched on 12 May 1914 and 25 July 1914, and named Ciucad di Buenos Aires and Ciucad di Montevideo respectively. *

Apparently Gibson encountered substantial opposition from within his company and in his own words; "When the first boat went on trials there were not wanting Jeremiahs who foretold dire disaster .... But for once, the prophets were mistaken, the end justified the means, and these blocks ran from the very first without the slightest trouble. Only the other day I saw the report from the engineer of one of the boats on her long voyage to the River Plate. He said 'Thrust Bearings ran quite cool with the chill not off!'". **

A typical very early Michell marine thrust bearing similar to those installed in the South American ferries is shown by figure 5. In this case the flat backed pads are supported by individually adjustable pivots. It was soon realised that this provision for axial adjustment of the pads was not only unnecessary but actually a source of potential calamity if errors were made in setting up. Accordingly the idea was soon dropped only to be resurrected and re-used in recent years in certain special applications such as very large vertical thrust bearings.

The first ship of the Royal Navy fitted with tilting pad main thrust bearings ran her trials in August 1914. The trials, like those of the Paris and the two Cammell Laird vessels must have been completely successful for in the discussion of a paper by Ward (13), Gibson commented that the Admiralty had thereafter adopted the single collar thrust whole heartedly and universally. Thus during the First World War Michell Thrust Blocks were fitted in British Naval Ships to propulsion machinery totalling ten million shaft horse power, (8). A figure which reflects the huge shipbuilding effort made at the time; for example no less than 280 destroyers were launched from British Yards between 1914 and 1918 (15), as well as many other vessels, smaller and larger.

* We are indebted to Mr. A.C. Hackman of Cammell Laird and Co. Ltd. for this information.

** From a paper on 'Geared Marine Steam Turbines' read by J. Hamilton Gibson before the Foreman's Mutual Benefit Society, Birkenhead, on 30 March, 1915, and quoted by H.T. Newbigin, The Michell Bearing Book, April 1916.