DESIGN, MANUFACTURE AND CHARACTERIZATION OF A JOURNAL BEARING DEMONSTRATION UNIT

S. N. Ojobor* and Nelson Nna Chidi*
Department of Mechanical Engineering
Enugu State University of
Science and Technology, Enugu.

ABSTRACT

The paper examines the potential for the indigenous design and manufacture of laboratory equipment used for demonstrating the engineering principles of taught courses in our Engineering Schools. Using the Demonstration Journal Bearing as a case-study it is shown that imaginative modifications to classical design could result to a prototype within the technical capability of our local skilled technicians and available machine-tools. It recommends that engineers in the private sector should work together with academia to popularize this potential, which, in addition to solving a chronic problem that holds ominous consequences for the survival of sound engineering practice for the nation in the years ahead, is going to be profitable in national image, even if not too lucrative, financially.

Keywords:- Laboratory equipment; engineering education; indigenous manufacture

Symbols Used

D	=	Bearing Diameter
h	=	lubricant film thickness
R	=	Journal radius
C	=	Radial clearance
e	=	eccentricity
ε	=	eccentricity ratio
f	=	friction coefficient
V	=	velocity
N	=	rotational speed
W	=	Bearing load
P	=	bearing unit loading
p	=	pressure
t	=	time
θ	=	angular position, from line of centers
Φ	=	Attitude angle
ω	=	angular velocity
L	=	bearing length
μ	=	dynamic viscosity

INTRODUCTION

Experimentation and the running of tests in laboratories are essential aspects of engineering education. Well equipped laboratories are essential for research and development. The technologically developed and developing countries who recognize the importance of engineering and technological research are continually increasing their annual budgetary allocation to Research and Development. Unfortunately laboratories in Nigerian Universities and Polytechnics are in contrast suffering continuous decay due to neglect. The equipment in the laboratories of many of the older universities are obsolete and have become almost scrap. Most of the younger Institutions have near-empty spaces in the name of laboratories.

The danger of turning out engineering graduates that are not firmly grounded with clear scientific understanding of the theories is a likelihood of having generations of engineers that are superficial and incapable of sustaining or advancing the frontiers of knowledge. The consequences are ominous; the technology gap between us and the Europe and America will continue to widen in astronomical proportion.

In realization of the now obvious fact that the various Governments are unable and/or unwilling to invest appropriately in higher education, this paper examines a small area where the Engineering Facilities and the general engineering community in the country may marginally employ self-help techniques to ameliorate the already disgraceful situation in many of our engineering schools. Since fund is scare to procure embellished and high-precision laboratory teaching equipment from abroad, perhaps we should tool up for local production by exercising our imagination and ingenuity and using our heads and hands in our local situation. We may end up with replacements/alternatives that will be good enough to demonstrate those fundamental engineering principles even if they fall short of the precision of imported equipment.

This paper is a case-study of one such effort at the Enugu State University of Science and Technology where a journal bearing demonstration unit was designed, manufactured and tested. It was made feasible by the well-equipped workshops of the Federal Government's Science Equipment Institute (SEDI) Akwuke, Enugu, and their high manufacturing skill in glass, plastics, metal and wood.

JOURNAL BEARING DEMONSTRATION UNIT: AN OVERVIEW

This apparatus is to be used in the field of Tribology with special emphasis on hydrodynamic lubrication. It should enable students to undertake tests to establish the relationship between pressure, rotational speed, eccentricity and load variations on the performance of journal bearings. This apparatus is intended to be simple, easy to operate and maintain; and powered from a regular AC mains supply voltage of 220v – 240v.

The history of journal bearing development started with the refinement of the hydrodynamic theory of lubrication. In 1883 Petroff made his significant contribution when he published his Petroff's Equation which linked the friction f, with the characteristic dimensions of the bearing radius, r, radial clearance, c; rotational speed, N, bearing load/pressure, p; viscosity μ)

$$f = 2\pi^2 (R/c)(\mu N/p) \qquad (1)$$

on the assumption of a concentric journal and bearing. The present form of the theory of hydrodynamic Lubrication owes a lot to the

Laboratory of Beauchamp Tower in the early 1883's in England, though the road to solid understanding fluid friction has been long and tortuous. Leonardo Da Vinci in 1515 investigated dry friction by attaching a line (rope) to a ship's cable laid out along a dusty road. Amontons, a Physics student, in 1699 stated that the coefficient of friction was the same for all metal-on-metal combination, and it was 0.3, but Columb in 1781 distinguished between static and dynamic (sliding) friction.

During the industrial revolution, Towers, in 1883, discovered the pressure rise in a bearing due to viscous pumping and Petroff in the same year discovered his equation relating coefficient of friction, shaft speed, viscosity of oil, pressure, projected bearing area, shaft radius and radial clearance. Osborne Reynolds in 1886 developed the differential equations that quantitatively describe film lubrication for both side leakage and non-side leakage. In 1904, Sommerfeld solved the differential equation for the journal bearing with no side leakage. Dr. Albert Kingsbury over the years, 1912 to 1915, developed film thrust bearings for which he used electrical analogue circuit to solve Reynolds' differential equation for side leakage in thrust bearings.

It was not until 1952, that Albert A. Rainmondi and John Boyd of Westinghouse Research Laboratories in New York, used the digital computer to solve Reynolds' differential equation for journal bearings in generalized formats. Their solutions were presented in dimensionless form and available to designers as charts.

THE BASIC PRINCIPLES

A Journal bearing essentially comprises the journal or shaft and a bearing, which is a cylindrical housing. An oil cup is attached on one side to the housing where a passageway leads to the oil hole of the bushing. An axial oil groove is also made in the bushing. A journal bearing reduces frictional effect and loss of power, heat generation, and wear of mating surfaces. The primary function of the lubricant in journal bearing is to prevent metal-to-metal contact between the rubbing surfaces. This is achieved through the formation of a lubricant film. As the lubricant is introduced into the bearing, the action of the rotating journal is to pump the lubricant into a wedge-shaped space, thus, forcing the journal over the other side. A minimum film thickness occurs, not at the bottom of the journal, but displaced clockwise from the bottom.

PRESSURE EQUATION FOR A LUBRICATING FILM

Reynolds Equation

The differential equation which governs the pressure in a lubricating film is called the *Reynolds Equation* [1]. Bearing performance can be evaluated once the solution of this equation can be obtained.

Reynolds bearing equation was developed by consideration of the Navier-Strokes equations to a fluid element in the bearing-journal cavity. The underlying principle is a statement of a Force-Balance in the bearing system; viz: -

Inertial forces = pressure forces + body forces + viscous forces [1]. As Navier-Strokes equations in its complete form are too involved. Simplifying, yet practical, assumptions are often made: -

(i) The flow is laminar
(ii) The inertial and body forces are small

compared to the pressure and viscous forces

(iii) The curvature of the film is negligible

(iv) The variation of pressure across the film $\partial p/\partial y$ is negligibly small, etc.

Application of these assumptions to Navier-Strokes yielded the *Reynolds equation* for a liquid-lubricated bearing:-

Journal And Bearing Notation

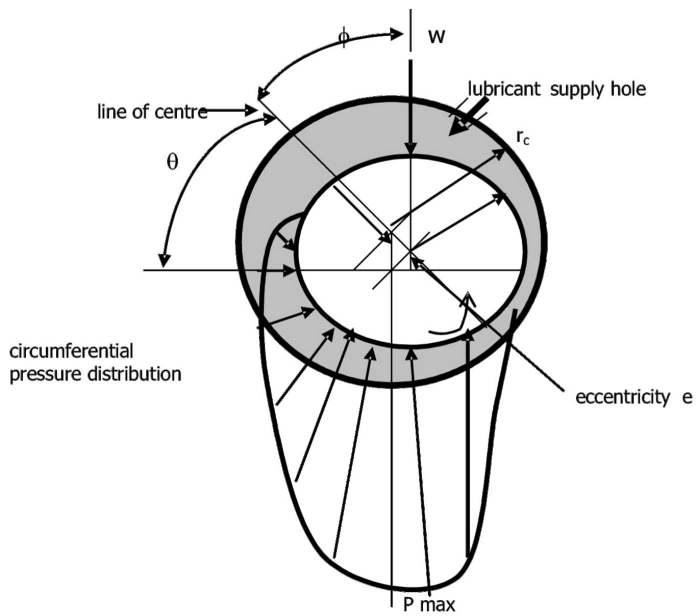


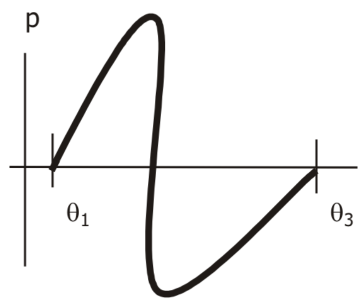
Fig.1 Journal Bearing; scheme and nomenclature

The Reynolds Equation links lubricant circumferential pressure flow, $(\partial p/\partial x)$, the axial pressure flow, $(\partial p/\partial z)$, to the Shear flow, $\mu(\partial V/\partial x)$.

$$\partial/\partial x\,(h^3(\partial p/\partial x)) + \partial/\partial z\,(h^3) = 6\mu\, R\omega\,(\partial h/\partial x) + 6\mu h(\partial V/\partial x) + 12\mu(\partial h/\partial t) \qquad (2)$$

One example of the complete solution to the above Reynolds' Journal bearing Equation is due to Sommerfeld; using the Sommerfeld circumferential boundary conditions as below [1]: -

Names associated with boundary conditions	**Pressure profile**	**Mathematical expression**

Sommerfeld (full Sommerfeld)		$p(\theta_1) = (\theta_3) =$ (i.e. ambient atmospheric Pressure) For complete journal bearings: $\theta_1 = 0, \theta_3 = 2\pi$ For partial journal bearings: $\theta_1 = \theta_3 = \theta_1 + \beta$

The total load on the journal bearing is supported by the hydrostatic pressure developed. The load per unit of the projected area of the bearing is given by:-

$$P = W/LD \qquad (3)$$

A dimensionless parameter that has come to be used as indicative of bearing performance is given by:-

$$\text{Sommerfeld Number} = (R/c)^2 \mu N/P \qquad (4)$$

The relationship that links bearing friction with the characteristic dimensions of the bearing, is:-

$$R/c.\ f = \Phi(R/c)^2 \mu N/P \qquad (5)$$

The Sommerfeld Number and the Sommerfeld Pressure Curve have become veritable parameters for assessing Journal bearing performance. Performance is generally measured in terms of four quantities: bearing load capacity, frictional losses, lubricant flow requirement, and temperature rise.

MANUFACTURING THE DEMONSTRATION UNIT

The Demonstration unit is designed and manufactured using entirely local resources

Material Selection

The materials were selected purely on the basis of availability and cost and their ability to fairly meet the functional requirements [2, 5].

The following materials were selected for the various components:

Table 1: Materials of manufacture of journal bearing

S/No	Part	Material	Justification
1.	Journal	Steel	Tough, easily machined; available also as stainless steel for long term corrosion-free operation
2.	Manometer panel	Rubber	Flexible tube: low friction, non-breakable, transparent, cheap
3.	Control unit	Brass	Standard materials, cheap and available

4.	Earing	Plastic perspex	It is easily machinable and formed into shape. Does not corrode
5.	Bearing weights	Mild steel	Rigid and tough, cheap
6.	Standing frame	Angle bar (mild steel)	Good rigidity and toughness
7.	Electric motor	1.5kW, 220 - 240v, 50Hz, 1430rpm	Available, affordable and suitable for easy connection to a routine power source.

PRODUCTION OF THE BEARING

The bearing is made of a clear acrylic material (Perspex). Processes of production include marking out the dimensions, cutting out the work-pieces, drilling, heating and forming of the work- piece.

Production of the Journal

The shaft, couplings and screws are produced, using general purpose machine tools in a normal mechanical engineering machine shop. What is paramount here is the skill and diligence of the operators so that, within the limitations of general purpose machine tools the highest precision may be achieved.

The probe-holes for pressure monitoring were drilled circumferentially on the bearing with 1.5mm diameter drill bits, being the smallest size available. Ideally, these probe-holes should not exceed 1.5mm diameter if laser-drilling equipment were available, so as to cause the minimum distortion to the journal bearing pressure profiles.

CHARACTERIZING THE DEMONSTRATION UNIT

The reservoir is first filled with the oil up to a level just below the tip of the supply pipe. The direction of rotation of the electric motor, clockwise or anticlockwise is selected. This is achieved by reversing of the polarity of the connection to the electric motor.

The motor is then powered and allowed to run at about 850rpm on a light load for about 50 minutes. This is to warm up the bearing.

With a speed of 600 rpm, as a test speed, a load of 100g is attached to the load arm beneath the Perspex bearing. The pressure profiles at various tapings are observed on the manometer panel. Later, the second, and third loads of 100g each are attached and the pressure profiles are taken and recorded. The same process is repeated for other speeds of 800rpm and 1100rpm, which is achieved using the speed control unit.

Data Values for the Demonstration Unit:

Radius of shaft	=	25mm
Diameter of bearing	=	55cm
Radial clearance, c,	=	2.5mm
Length of shaft, *L*	=	70mm
Static pressure head, hs	=	40cm

The plot below fig 2 shows pressure curves of the Demonstration Unit. The curve may be compared to the Sommerfeld homologous bearing available in literature [1].

DISCUSSION OF RESULTS

The results are in the general pattern of well designed and manufactured journal bearings. The pressures in the fifteen pressure tappings are by and large in orderly distribution except in No.4 position. This distortions may be explained by manufacturing imperfections. The pressure is negative in some locations as is expected, representing the low pressure regions. Naturally, with only three test speeds; and such low values of bearing loads the classical shift in the location of maximum film pressure is hardly noticeable.

Cost of the Demonstration Unit

The cost of the Journal Bearing Demonstration Unit is about ₦20,000 (Twenty seven thousand naira) inclusive of materials and labour. An imported substitute in 2008 price is F.O.B. ₤3000 (three thousand pounds sterling)

speed(rpm)	Load(g)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
600	100	14	14	14	18	23	32	36	-5	-40	-20	-8	-2	0	2	7
1100	100	20	20	20	24	30	35	42	-11	-46	-26	-14	-8	-2	6	13

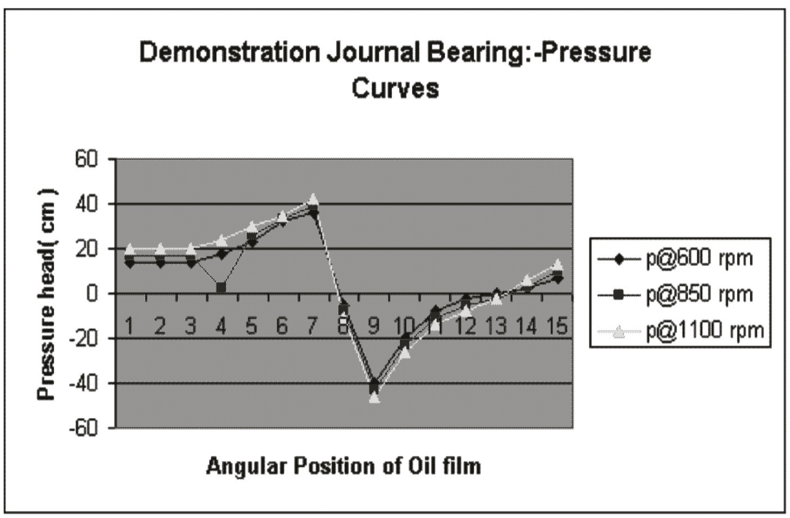


Table 2: Pressure readings at tap holes

CONCLUSION AND RECOMMENDATIONS

This paper is not so much a treatise on Journal bearings as it is on the possibilities/opportunities for local manufacture of laboratory teaching aids for Engineering faculties in our tertiary institutions. It is our submission that engineers in the private sector can profitably work hand in hand with the academia and demystify most of our hitherto imported laboratory equipment, through careful study of available manufacturer's brochures and referencing the enormous pool of information from Internet. That will surely be one attempt at survival and appropriate a response to country that reckons very little with her best assets, the education of a future generation.

REFERENCES

1. Shigley, J. E., Mischke C.R "Standard Handbook of Machine Design", (sixth edition), New York, America, McGraw-Hill Publishers.
2. Deharmo, E. P., "Materials and Processes in Manufacturing", (fifth edition), Collier Macmillan, 1984.
3. Ojobor, S. N. "Adaptive Approach to Design, material selection and production processes for local manufacture of equipment machine", Raw Materials Research Council Conference, Ibadan, February 1991.
3. Chukwujekwu, S. A. "Role of Government and Private Sector in driving innovation and hyman capital development, UNIDO Abuja conference, 2002.
4. Brook, G. B., "Advanced Materials Technology, 1990, Stirling Publication Ltd London.
5. Redmond, W.A, Microsoft Encarta 2009; "Bearings (mechanics)"; Microsoft Corporation, 2008.