Introduction

Development in the field of science and technology has resulted in requirements for high performance bearings operating in extremely difficult working conditions. Some of the challenging applications can be found in the areas of Cryogenic systems, Computer hardware, Space applications, I.C engines and high speed turbomachinery.

Lubrication plays an important role when loads have to be transmitted between two bodies in relative motion. Lubrication is one of the important means of lowering frictional resistance. If two mating surfaces are separated by a lubricating film, such a type of lubrication is commonly known as fluid film lubrication. Different applications, however, require different types of lubricants such as solid, liquid and gaseous. Bearings operating under fluid film lubrication are called fluid film bearings. The most widely used bearings in industries are radial or journal bearings where the applied load is in the radial direction.

Fluid film bearings work mainly on two principles (i) hydrodynamic or self-acting and (ii) hydrostatic or externally pressurised.

In hydrodynamic bearings the oil film pressure is developed because of their geometry (convergent-divergent film) and operating conditions. Hydrodynamic pressure can also be developed if the lubricating film exists because of the oscillating relative normal motion, and such bearings are called the squeeze-film bearings. However, under normal operating conditions, the hydrodynamic pressure will be the result of wedge action. The magnitude of the pressure developed depends on relative tangential or normal velocity, viscosity of the lubricant, shape of the clearance space, etc.

In some operating conditions, where the load is high or the speed is low, the hydrodynamic lubrication fails. Externally pressurised (or hydrostatic) bearings have been found to be useful in these situations. Here the pressurised oil is supplied to the bearing clearance from an external source usually via a restrictor.

The hydrodynamic theory of lubrication stems out of the experiments of Tower [1] and their interpretation by Reynolds [2]. Reynolds [2] derived the basic differential equations and Sommerfeld [3] simplified and extended this theory. The works of Reynolds [2] and Sommerfeld [3] served as basis for further research in this field.

With the continuous increase of operating speed and load in the rotating machinery and also better manufacturing processes there is a growing tendency towards the "limit design". For this it is important to predict the bearings operating characteristics more realistically considering additional effect such as the surface roughness. Since the film thickness is of the order of a few micro-meters, the surface topography exerts a profound influence on the performance of bearings. Tzeng and Saibel [4] made pioneering contributions with the introduction of the stochastic process concept. Later, Christensen [5] and Christensen and Tonder [6, 7] provided a definite foundation for studying the surface roughness effects in hydrodynamic bearings. This opened up a new field which attracted several researchers to study the influence of surface roughness on the lubrication phenomena. Since then several models have been suggested by various authors to describe the surface roughness which also consider contact between the surfaces. In recent years this field has been receiving fresh interest with the aim of using the beneficial effects of surface roughness patterns and also to possibly estimate the exact extent of finish machining operations thus saving on manufacturing costs [8].

The problem of oil-whirl instability in journal bearings is a well recognised one. Rotor when subjected to oil-whirl besides spinning in the normal manner, wobbles around in the clearance space of the bearing. The most important feature of oil whirl instability is that, unlike the critical speed resonance, the amplitude of whirl often does not decrease after the onset speed has been passed. On the contrary, it increases with increasing speed. If corrective measures are not taken, the high amplitude vibrations may result in excessive wear, fatigue and seizure.

From the time hydrodynamic instability was first reported, extensive investigations have been carried out to predict and improve the stability of rotor-bearing systems. There are primarily two approaches to study the stability characteristics of rotor-bearing systems: the linearised perturbation and the non-linear transient techniques.

For small rotor displacements stiffness and damping coefficients have been obtained by means of linearised perturbation technique from the governing Reynolds equation. Using these coefficients threshold of oil whirl instability and whirl ratios have been calculated. This method has been extremely popular because of its simplicity and limited computational requirements. But the load-displacement characteristics of a journal bearing is non-linear, and this leads to substantial errors at high eccentricity ratios and also in situations where significant dynamic loading is encountered. In the case of dynamic loading, such as in crank shaft bearings, nonlinearity renders the use of a single set of stiffness and damping coefficients totally impractical. Hence it is argued that analysis based upon an assumption of small vibration amplitudes has its limitations. For this reason, where computational resources permit, a non-linear approach to oil-whirl instability analysis is preferred. Moreover, the trajectory of journal centre due to a disturbance from the equilibrium position can give a better insight into the dynamic behaviour of a journal bearing system rather than a number which simply determines if a system is stable or unstable.

Although the non-linear transient analysis of journal bearings is time consuming and requires greater computational capabilities, this problem is no longer proving to be an obstacle with dramatic increase in the available computational power. It is believed that the computational power is more than doubling every two years with a corresponding reduction in costs.

The earlier work reported in literature using the Christensen's model of surface roughness deals with only steady state characteristics. Stability analysis using the linearised perturbation technique for some specific surface patterns is just being reported in literature. In the present work steady-state and dynamic characteristics (linear and non-linear transient analysis) of hydrodynamic journal bearings with rough surfaces using the Christensen's model of surface roughness have been studied. The stochastic finite element method has been used to model the Reynolds type equations. The stiffness and damping coefficients obtained from the linearised perturbation technique have been used to study the unbalance response and stability of a flexible rotor supported on journal bearings with rough surfaces.

The thesis is divided into seven chapters.

- The first chapter reviews the literature published in this field with specific reference to the problem under investigation.

- In the second chapter the basic equations used in this study have been derived. This will be helpful for easy and ready reference.

- The third chapter deals with the steady-state characteristics of hydrodynamic bearings with rough surfaces. One-dimensional and finite slider and journal bearings have been considered. Slider bearings for different b/L ratios and journal bearings with various b/d ratios have been studied. The stochastic finite element formulation has been given and used.

- In the fourth chapter dynamic characteristics of a rigid rotor supported on hydrodynamic journal bearings with rough surfaces has been studied using the linearised perturbation technique. Stiffness and damping coefficients and stability characteristics (in terms of $\bar{M}$ and λ) have been found for different b/d ratios.

- In the fifth chapter non-linear transient analysis has been performed on a rigid rotor supported on hydrodynamic journal bearings with rough surfaces to study the sub-synchronous whirl instability. Journal centre trajectories have been plotted for bearings of different b/d ratios to ascertain the status of the system(stable or unstable).

- The sixth chapter deals with the unbalance response and stability of a flexible rotor supported on hydrodynamic journal bearings with rough surfaces. Bearing stiffness and damping coefficients obtained in the chapter four have been used with suitable coordinate transformations.

- Conclusions and suggestions for further work based on this study are presented in chapter seven.

- A list of references is given at the end.