Theory and Practice of Rotor Dynamics
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Lecture - 3
The state of art of rotor dynamics

Today we will be covering rotor dynamics, what are the state of art, we will continue in the previous lecture which we were describing the history of the rotor dynamics. We already saw the history of the rotor dynamics in which people solve the problem of the critical speed reduction and unbalance behavior critical speed all. So, we saw some of the instability which arises in the rotor due to asymmetric in the shaft or asymmetric in the rotor itself. Now, we will continue with instability in the rotor system. So, I have given this particular lecture in the state of the art rotor dynamics.

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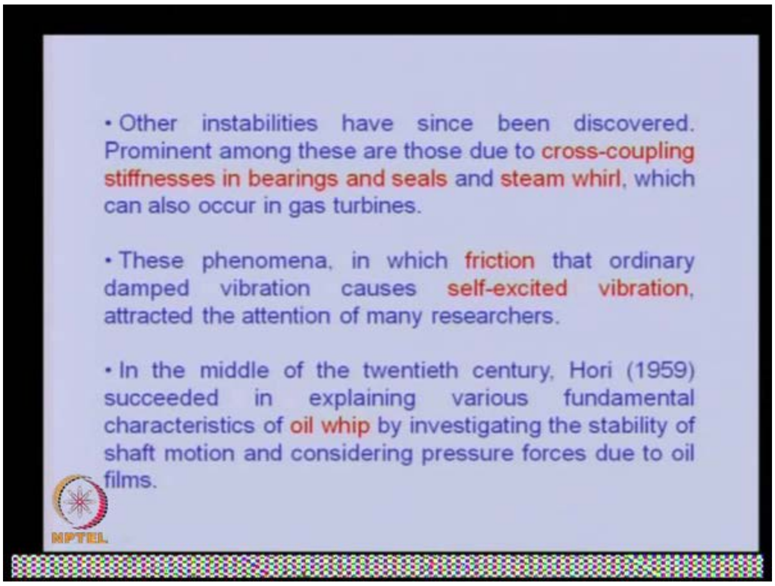

Other instability have been discover permanent among these or cross coupling stiffness wearing and streams and stream fold which also occur in guest appearances. This phenomena reaction that ordinarily dept by causes exaltation vibration attract, the attention of many researches in the middle of 20th century, in 1959 succeeded in achieving various fundamental characteristic of oil whip by investing the stability of shaft motion and consideration pressure forces due to oil films.

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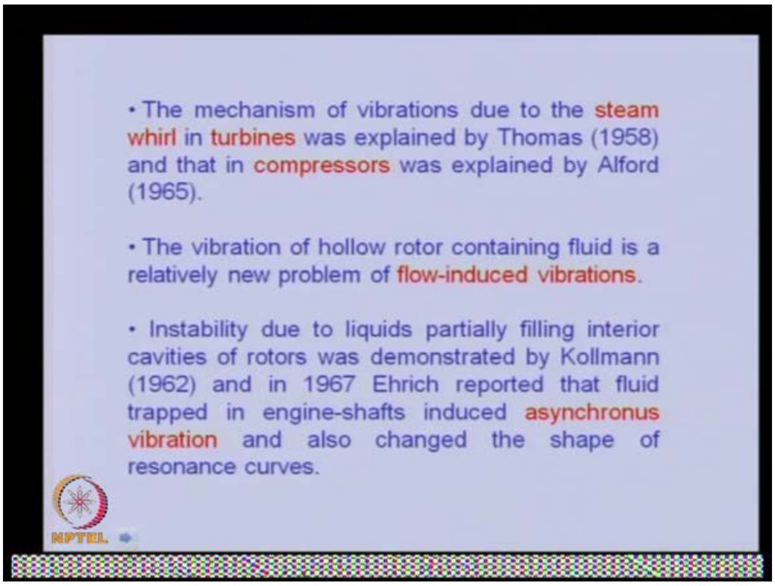

The mechanism of vibration due to the stream whirl in turbine was explained by Thomas in 1958 and the compressor was explained by Alford in 1965. The vibration of hollow rotor containing fluid is a relative new problem of flow induced vibrations. Instability due to liquids partially filling interior cavities of rotors was demonstrated by Kollmann in 1962 and in 1967 Ehrich reported that the fluid trapped in engine shafts induced asynchronous vibration and also changed the shape of resonance curve.

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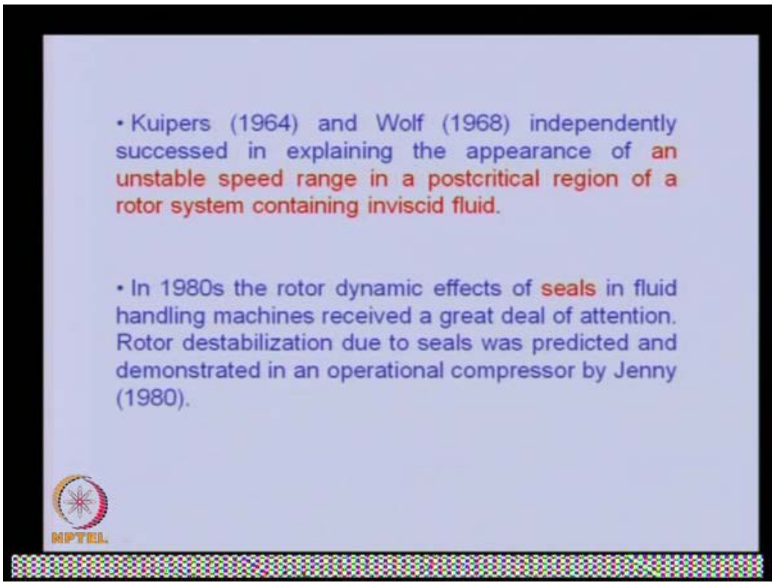

Kuipers in 1964 and Wolf in 1968 independently succeeded in explaining the appearance of an unstable speed range in a post critical region of a rotor system containing in viscid fluid. In 1980 the rotor dynamics effects of seals in fluid handling machine received a great deal of attention. Rotor destabilize due to seal were predicted and demonstrated in an operational compression by Jenny in 1980.

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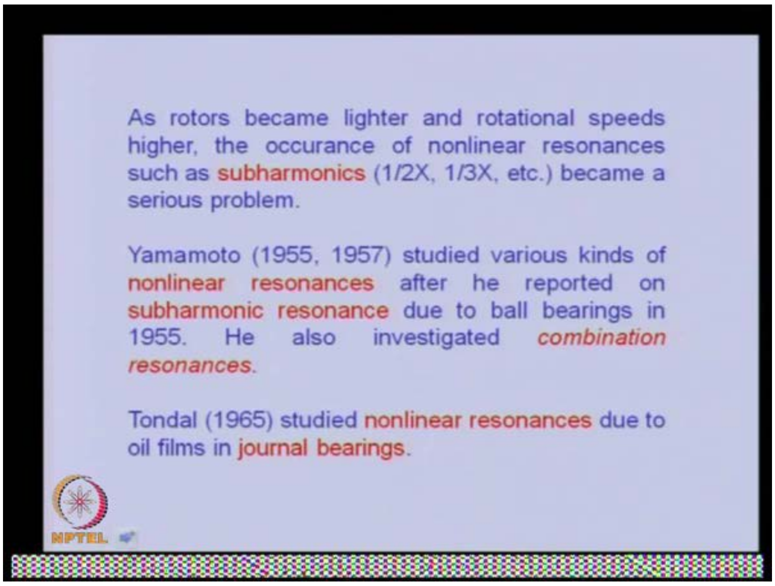

As rotors became lighter and rotation speeds higher, the occurrence of non-linear resonances such as sub harmonics half x, one third x, etc became a serious problem. Yamamoto in 1955 and 1957 studied various kinds of non-linear resonances after the reported he reported on some harmonic resonances due to ball bearing in 1955. He also investigated combination resonances. Tondal in 1965 studied non-linear resonances due to oil films in journal bearings.

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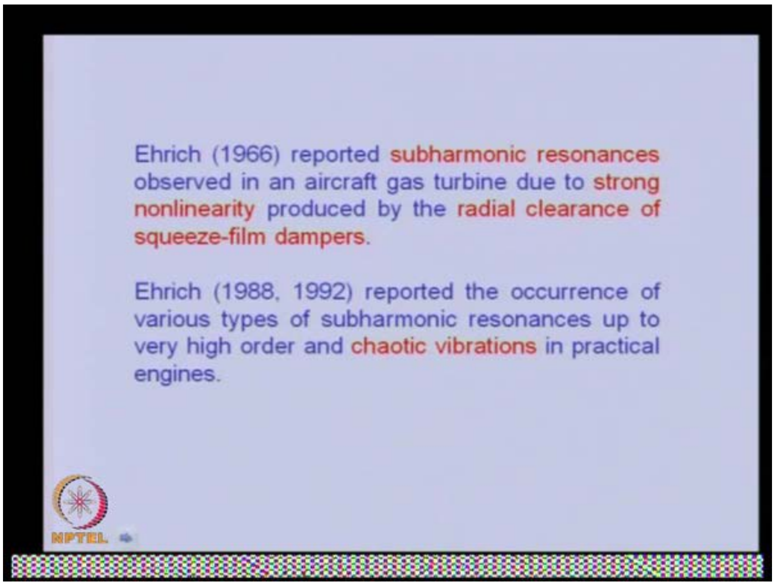

Ehrich in 1966 reported sub harmonic resonances observed in a air craft gas turbine due to strong nonlinearity produced by the radial clearance of squeeze film dampers. These squeeze films dampers are identical to the journal bearings, only thing is the squeeze film dampers stiffness property is journal bearing gives to the rotor is not there, only the damping consist to the rotor. Then Ehrich in 1988 and in 1992 reported the occurrence of various types of sub harmonics resonances up to high order and aquatic vibration in practical engines.

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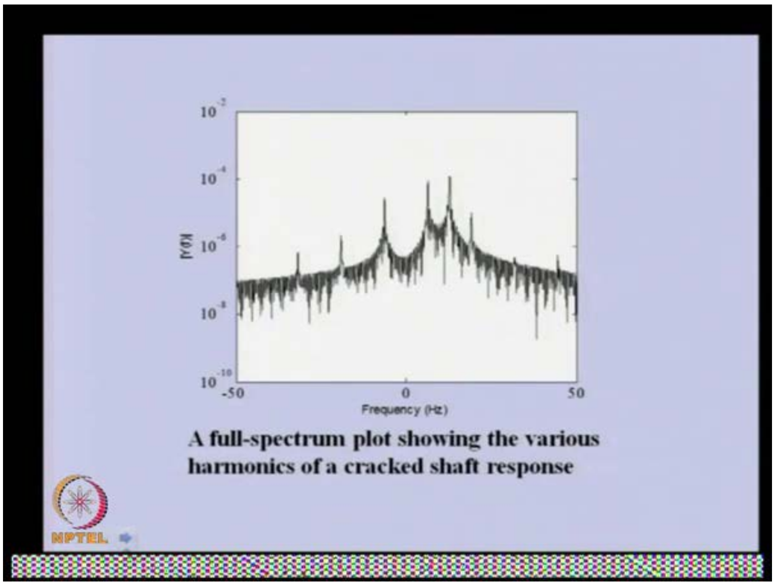

It is a typical full spectrum plot showing the harmonic, even the can able to the frequencies are there, not only in the positive side, also the negative side. We have seen earlier the concept of the forward hold and backward hold. You can able to see the some frequencies components which are negative side belong to the backward hole and positive side to the forward hold.

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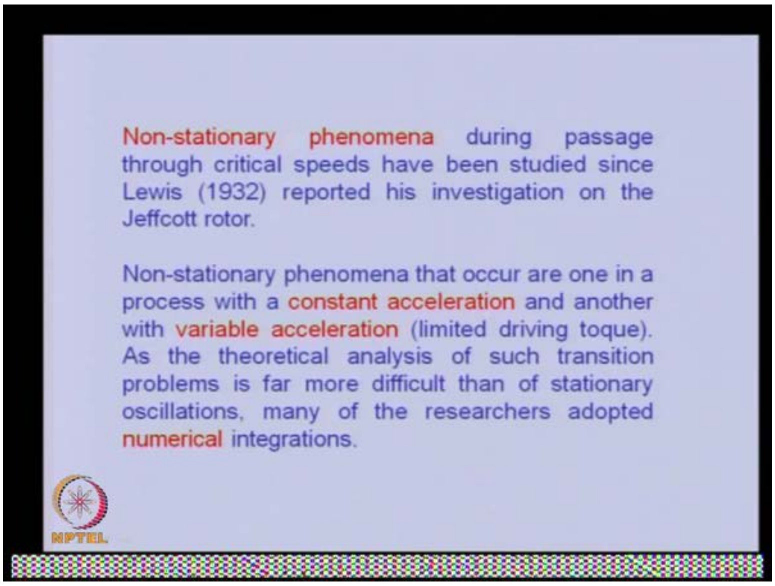

The non-stationary phenomena during passage through critical speed have been studied since Lewis in 1932 reported the investigation on the Jeffcott rotor. Non stationary phenomena that occur are one in a process with the consent and acceleration and another with a variable acceleration. In which we have limited the driving top at the critical analyses with conditional process is the former difficult, than the conditioner exultation many of the researches doctored memorical integrations.

In this particular region when we are considering tangent rotor analyses, you must have observed to avoid the critical speed that is to avoid the critical speed. Generally, the rotors are given very high accelerations so that they can cross the critical speed quickly and go to the super critical regions and during the accelerations the problem may come. If the driving motor drive is the sufficiently having the power, there will not be any problem in the whatever the acceleration we want to give, but in drive is having less power than the required acceleration will not achieved and will be having problem. That variable acceleration will have to take place.

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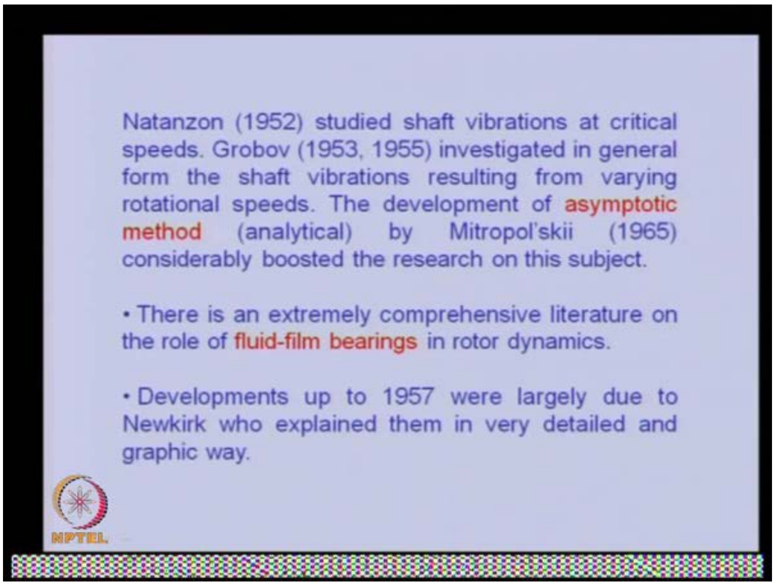

Natanzon in 1952 studied shaft vibration in critical speed. Grobov in 1953 and 1955 investigated in general form shaft vibration resulting from varying rotational speeds. The development of asymptotic method, that is analytical method by Mitropolskii in 1965 considerably boosted the researched on this subject. There is an extremely compressive literature on the role of fluid film bearing in rotor dynamics. Development of 1957 we are largely due to Newkrik who explained them in very detailed and graphical way.

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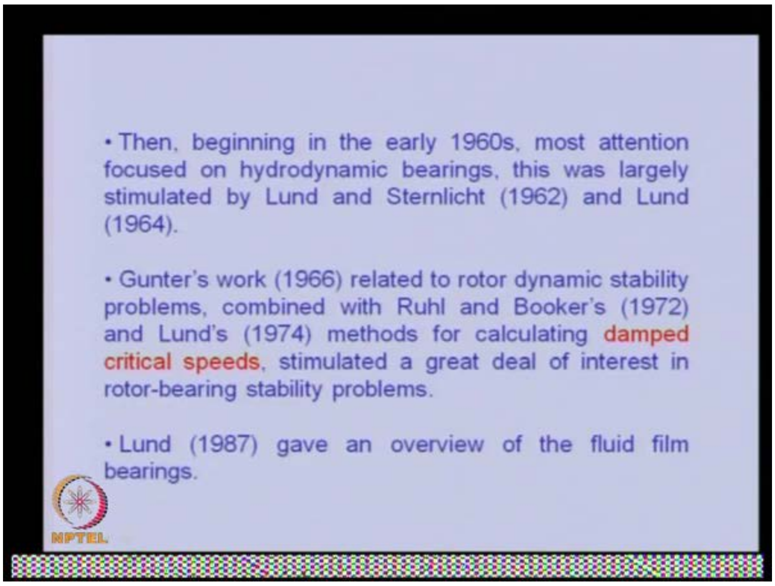

Then beginning in early 1960s, most attention on hydrodynamics bearings, this was largely stimulated by Lund and Sternlicht were in 1962 and 1964. Gunter's work in 1966 related to rotor dynamic stability, combined with Ruhl and Booker's in 1972 and Lund 1974 method for calculating damped critical speed, stimulated the great deal of interest in rotor bearing stabilizer problem. Lund in 1987 gave a overview of the fluid film bearing.

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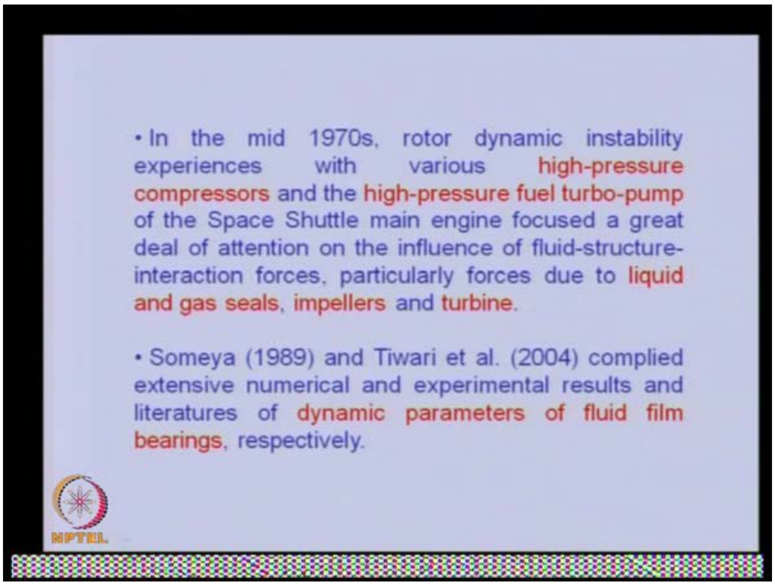

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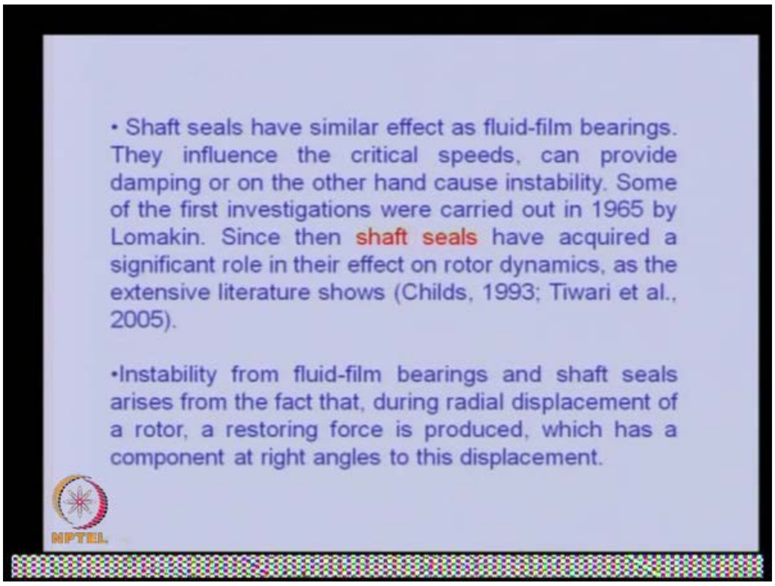

In the mid of 1970 the rotor dynamic instabilities experience with various high pressure compression and high pressure fuel turbo pumps of the space steel engine the great deal on the influence on fluid structure introduction forces, particularly forces due to liquid gas seals and turbines. Someya in 1989 and Tiwari in 2004 complied extensive numerical and experimental result and literatures of dynamic parameter of fluid film bearing, respectively.

Shaft sheld have the similar effect as fluid film bearing. They influence the critical speed, can provide damping and on the other hand cause instability, cause of the first investigation we have carried out in 1965 by Lomakin. Since than shaft seal have acquired a significant role in there effect on the rotor dynamics, as the extensive literature shows in Child book in 1993 and reveal late by Tiwari in two 2005. Instability form fluid film bearing and shaft seals arises from the fact that during radial displacement of a rotor, which has the component of displacement.

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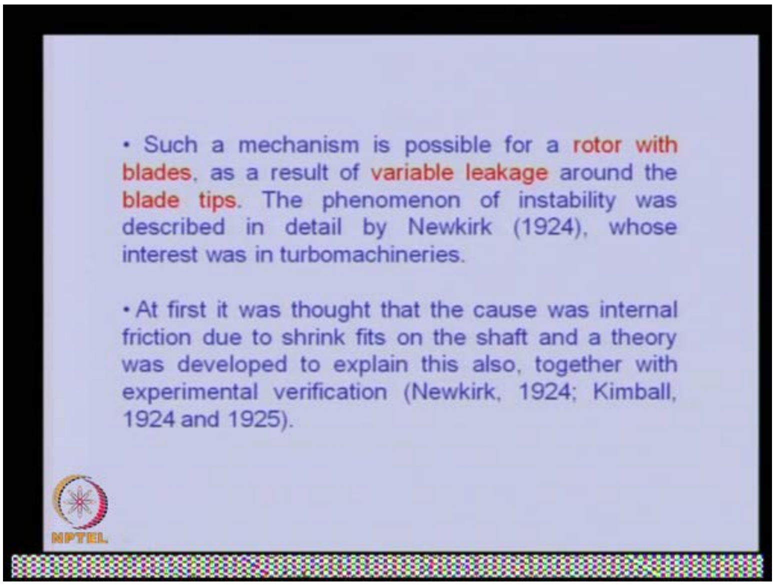

Such an mechanical is possible for rotor with blade, as the result variable linkage around the blood tips. The phenomena of the stability was exiled by Newkirk described in 1944, its interest was interest in turbo missionary. At first it was thought that cause internal fractions due to fraction of the shaft and the theory was developed to explain this also, together with experimental verification by Newkirk in 1924 also 2004, sorry in 1924 and 1925. Till now we have seen various literatures review related to rotor dynamic phenomena, how people are tempted to those phenomena and now let us try to summarize what we have studied in a tabular form.

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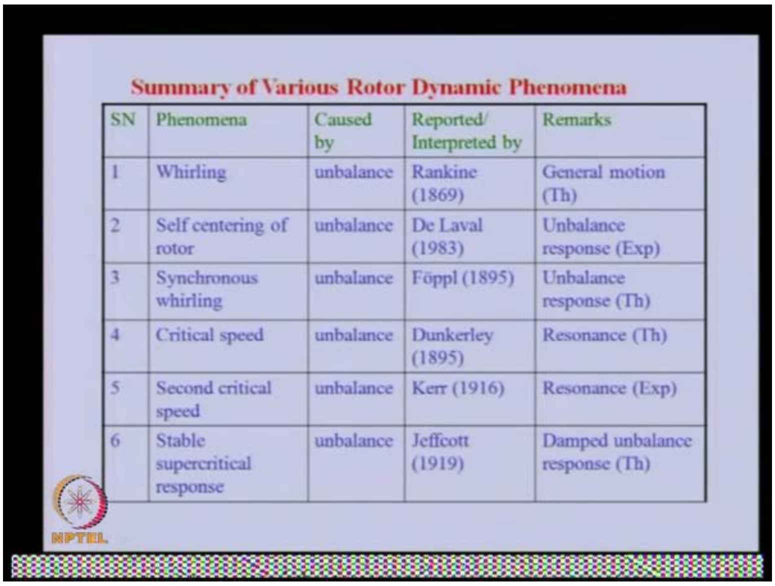

Summary of Various Rotor Dynamic Phenomena

SN	Phenomena	Caused by	Reported/ Interpreted by	Remarks
1	Whirling	unbalance	Rankine (1869)	General motion (Th)
2	Self centering of rotor	unbalance	De Laval (1983)	Unbalance response (Exp)
3	Synchronous whirling	unbalance	Föppl (1895)	Unbalance response (Th)
4	Critical speed	unbalance	Dunkerley (1895)	Resonance (Th)
5	Second critical speed	unbalance	Kerr (1916)	Resonance (Exp)
6	Stable supercritical response	unbalance	Jeffcott (1919)	Damped unbalance response (Th)

So, this is the summary of various rotor dynamic phenomena and there detail. It was like folding related to this particular was used in the Rankine in 1869 and this was critical work, which describe the general work of the rotor system, self-centering of the rotor. This concealed was introduce by Laval, Da Laval in 1883. I am again repeating this self-centering of the rotor was described in Da Laval in 1883, this is critical experimental work gives the unbalance work of the rotor.

Then it include the responding was introduced by Foppl in 1895, that is also analysis response and critical response. Critical speed was introduced by Dunkerey in 1895, the resonance of the phenomena, second critical speed was absorbed by Kerr in 1916. In his experimental set up stable super critical response was first analyses by Jeffcott, based on this analysis particular rotor model was available to the rotor dynamics stability and he described the damp analysis response of the rotor of critical speed also.

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Summary of Various Rotor Dynamic Phenomena

SN	Phenomena/effects	Caused by	Reported/ Interpreted by	Remarks
7	Secondary resonance	gravity	Stodola (1924)	Unbalance response (Th)
8	Instability	Shaft asymmetry	Prandtl (1918)	Instability analysis (Th)
9	Gyroscopic effect	Rotor wobbling	Stodola (1924)	Free vibrations (Th)
10	Threshold spin speed for instability	Internal damping	Newkirk(1924), Kimball (1924), Smith (1933), Crandall (1961)	Instability analysis (Th)
11	Threshold spin speed for instability	Dissymmetry of bearing stiffness	Smith (1933)	Instability analysis (Th)

Then secondary redolence due to gravity was explained by Stodola in 1924. This stability due to shaft ability Wapvendal in 1918, Jaliscopig effect that is ogling by it was described in the book in 1924. Threshold speed for instability due to internal damping was described by NewKerk Kembelance, threshold for instability. This similar this stability of various difference was described by Smith in 1933.

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Summary of Various Rotor Dynamic Phenomena

SN	Phenomena /effects	Caused by	Reported/ Interpreted by	Remarks
12	Oil whip	Nonlinear action of the oil wedge in a journal bearing	Newkirk and Taylor (1925)	Instability analysis (Th)
13	Self-excited vibration	Contact between rotor and stator	Baker (1933)	(Th)
14	Oil whip	Hydrodynamic bearing	Hori (1959)	(Th)
15	Steam whirl	Steam injection on turbine blades	Thomas (1958)	(Th)
16	Flow induced vibrations	Hollow rotor containing fluid	Kollmann (1962), Ehrich (1965), Kuipers (1964), Wolf (1968)	(Exp), (Exp), (Th), (Th)

Oil whip was observed by NewKerk Tentelar in 1925, self exhorted vibration due to contact was reported by Baker, oil hold in hydro dynamic was more detail described by

Orin in 1959, stream hold was reported in stream turban. Thomas in 1958 fold list vibration hollow region fluid was described by Colman alas both critical experimental.

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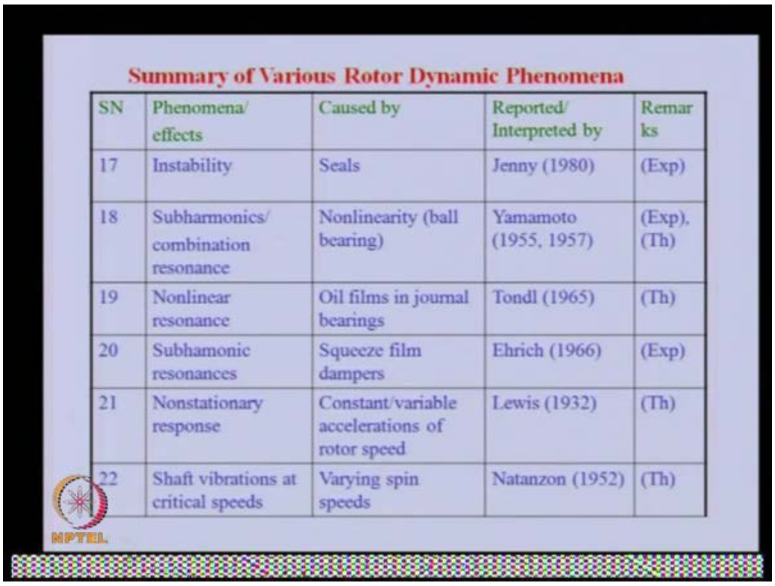

Summary of Various Rotor Dynamic Phenomena

SN	Phenomena/ effects	Caused by	Reported/ Interpreted by	Remarks
17	Instability	Seals	Jenny (1980)	(Exp)
18	Subharmonics/ combination resonance	Nonlinearity (ball bearing)	Yamamoto (1955, 1957)	(Exp), (Th)
19	Nonlinear resonance	Oil films in journal bearings	Tondl (1965)	(Th)
20	Subhamonic resonances	Squeeze film dampers	Ehrich (1966)	(Exp)
21	Nonstationary response	Constant/variable accelerations of rotor speed	Lewis (1932)	(Th)
22	Shaft vibrations at critical speeds	Varying spin speeds	Natanzon (1952)	(Th)

Works instability due to streams was reported by Jenny in 1980, some harmonics and resonance due to normal ball bearing was reported by Yamomotto in 1955 and 1957. Nominal fluidness to oil whip journal bearing was described in great detail by Condon in 1965, some harmonic redolence fluid damper was reported by Herich in 1966. Non stationary response due to constant and variable expense rotor speed was described by Lewis in 1932. Shaft vibration in critical speed spin speed was dealt with Natongen in 1952. Again I am repeating, shaft spinning at critical speed due to bearing spin speed was described by Natongen in 1952.

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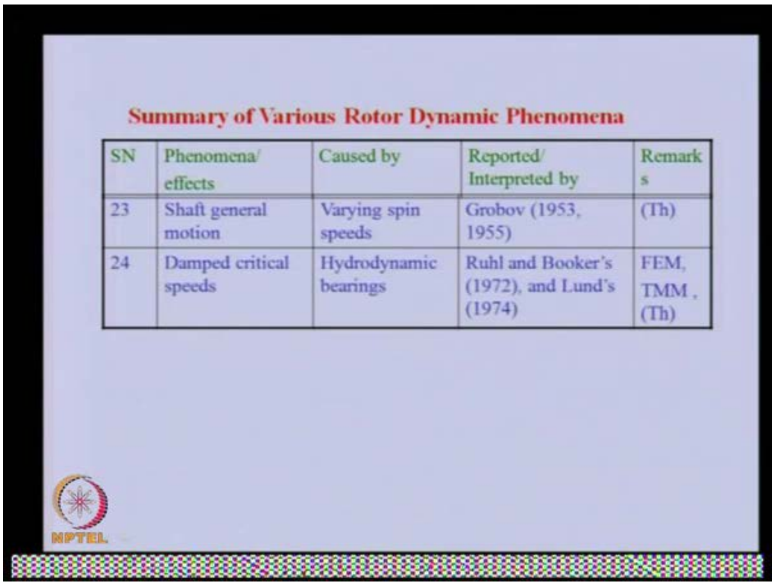

SN	Phenomena/ effects	Caused by	Reported/ Interpreted by	Remarks
23	Shaft general motion	Varying spin speeds	Grobov (1953, 1955)	(Th)
24	Damped critical speeds	Hydrodynamic bearings	Ruhl and Booker's (1972), and Lund's (1974)	FEM, TMM , (Th)

Then the shaft general motion, that is for varying spin speed was described by Grobo in 1953 and 1955 and damp critical speed of hydro dynamic speed was explained by Roo and Bokar in 1974. They use Fea and Fent, that is finite element method. That is for matrix method now we will begin with the another face of the fermentation in which will be it is the outline of the presentation.

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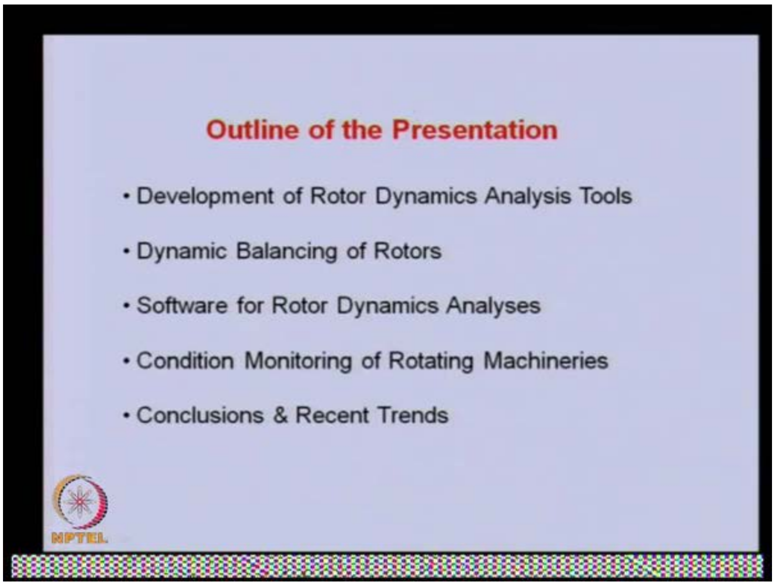

In which will be development of the rotor dynamic analysis tool I will be describing dynamic balancing of the rotors. That is how the development took place of fluid for rotor dynamic analysis, some of the software I will try to reveal. Then they will come to the condition of monitoring rotating machineries, a brief review on that and the concussion in the result end.

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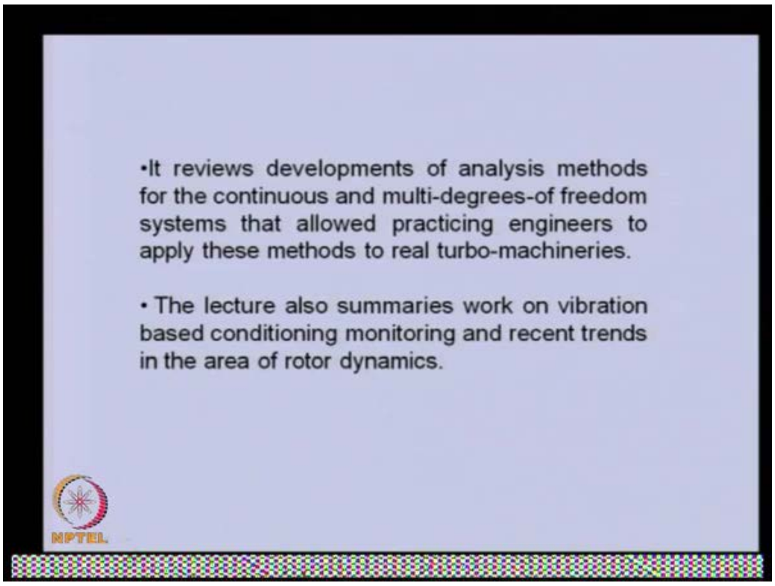

So, now we will reveal the development methods for continues as well as multi in that, allow practicing engineering, apply these method. The lecture also summarize the work on vibration based condition, result ends the area of the rotor dynamics.

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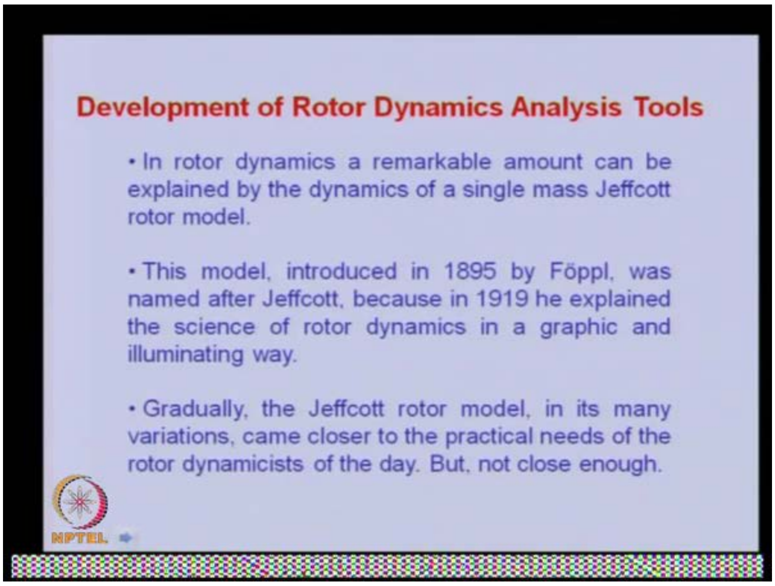

So, let us see the condition of the rotor dynamics analysis tools, the rotor dynamics remarkable development can we explain by the dynamics single Jeffcott model. We have seen that there was a confusion in the history of the rotor dynamics, Jeffcott total Jeffcott the confusion and because of this because of this particular outer model very popular and very analyzer sing, the most of the simple rotor behavior. So, this model introduced in 1895 by Fafel was named after Jeffcott because in 1990. He explained the science of rotor dynamics, graphical and availability work, gradually the Jeffcott model in its variations came closer to the particle rotor dynamics of the day are close enough.

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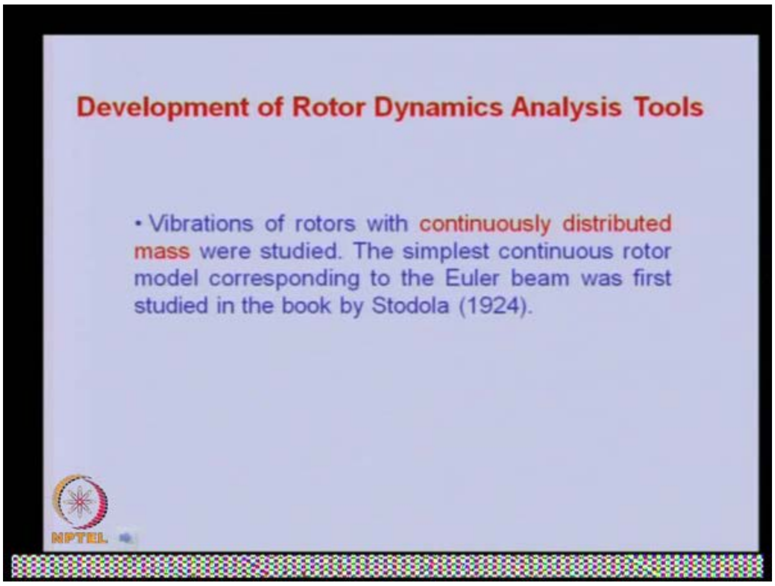

Vibration of the rotor continues to mass, we have studied in the rotors acutely. We can able to model that disc ripe matches or continuously distributed property, easily distributed property. Both the mass and the stiffness of the shaft were is along the length of the shaft, but in discrete system the lumped masses are collected by mass of spins. So, these are two different models, as we go into the subject more detail we can able to appreciate. So, the simplest continuous rotor model corresponding to the angler pipe was first studied by the book by Stodola in 1924.

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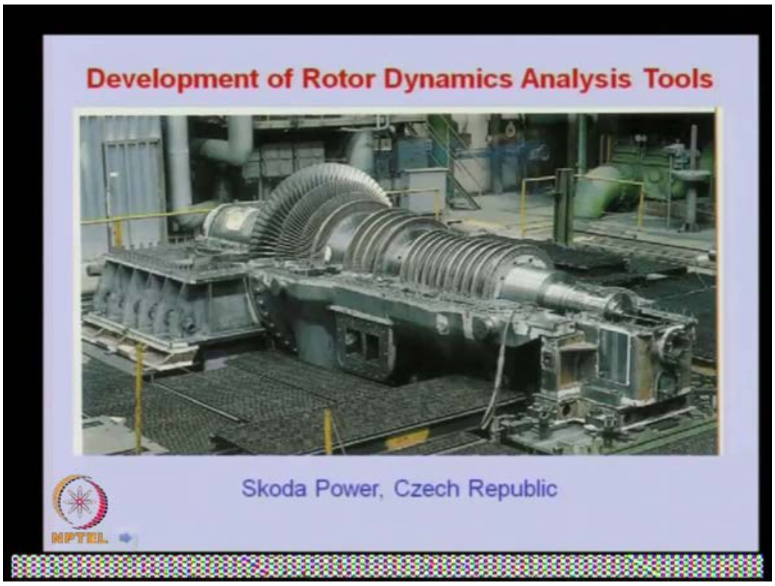

This is the typical turbine which we can able to analyze, a present whatever the analyzers tools are available.

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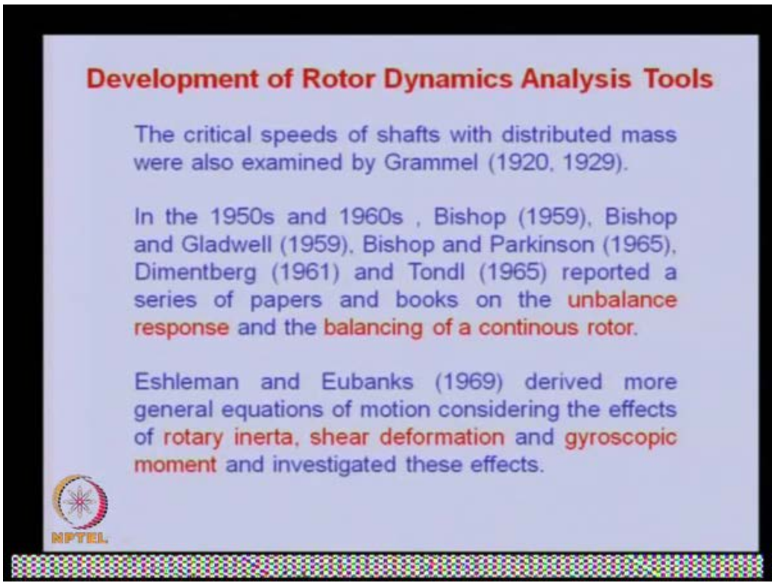

The critical speed of the shaft is to rotate the mass were we also examine by Gramin in 1920 and 1929. In 1950 and 1960, the echo workers like Parkenshan Getwel, they allow with the Demembal Tonden. They reported the crease of the paper books on unbalance response and the balancing of continues rotors. Eshleman and Eubanks in 1969 derived more general equation considering the effects of rotary inertia, share reformation, gyroscopic movement investigated this effect. The rotary inertia, shared reformation, gyroscopic effect these are generally called the higher effect rotor dynamics. We will see that has we go into deep into the subject, how this phenomena, this effect, they effect the natural critical speed of the rotor system.

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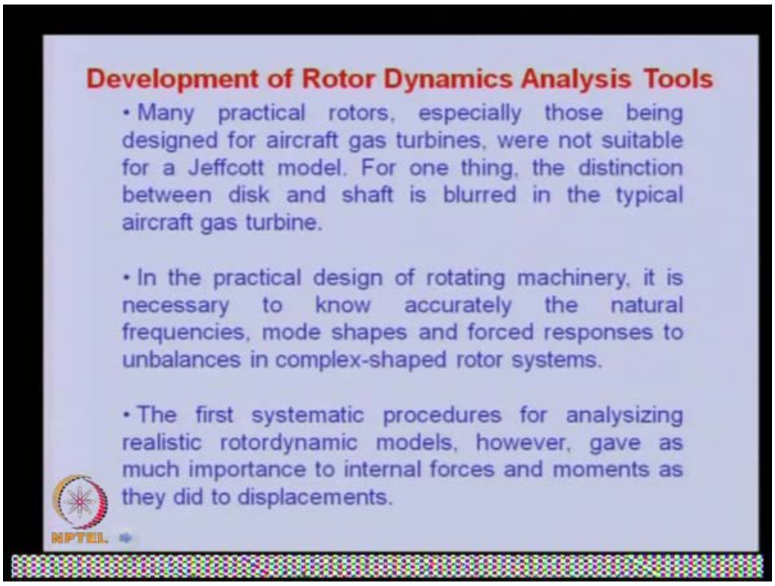

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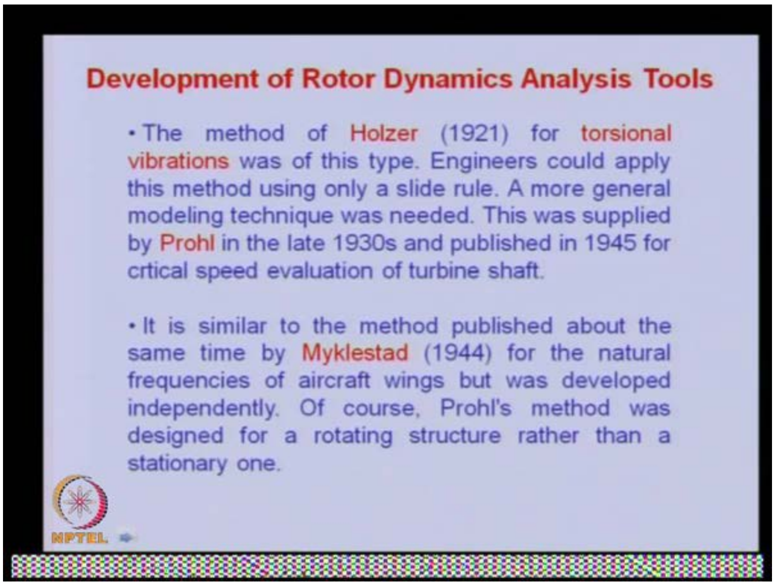

Many practical rotor, especially those being designed for air craft gas turbines. We are not suitable for Jeffcott model or one thing, the distension between disc and shaft is blurred in the typical air craft turbines. In the particle of rotor designing, it is necessarily to know accurately the natural frequencies. Both shape and responses or balance in the complex rotor system. The first systematic procedure for analyzing the rotor model is much important to internal dowel as the movement to the displacement.

The method of Holzer in 1921 for torsional vibration was this type. Engineers could apply this kind of side rule a more general modeling was needed. This was supplied by Prohl in the late 90s, then published in 1945 or critical speed evolution of turbine shaft. It is similar to the method published about the same time by Myklestad in 1944 for the natural frequencies of aircraft wings, but was developed independently. Of course, all the method was designed for the rotating structure rather than stationary one.

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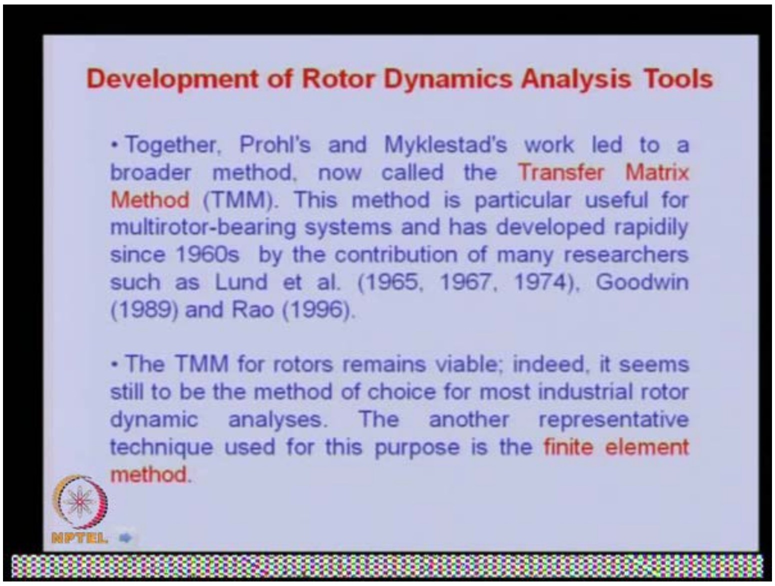

Together, Prohls and Myklestad let to a broader method transfer matrix method of TMM. This method is particular suitable for useful for multi rotor varying systems and has developed rapidly since 1960s by the contribution of many researches including Lund, Goodwin, Rao, etc. The TMM or the transfer matrix method rotor remains viral, indeed it seems still to be method of choice for most hysteria dynamic analysis, the another representative technique for the purpose of finite element method.

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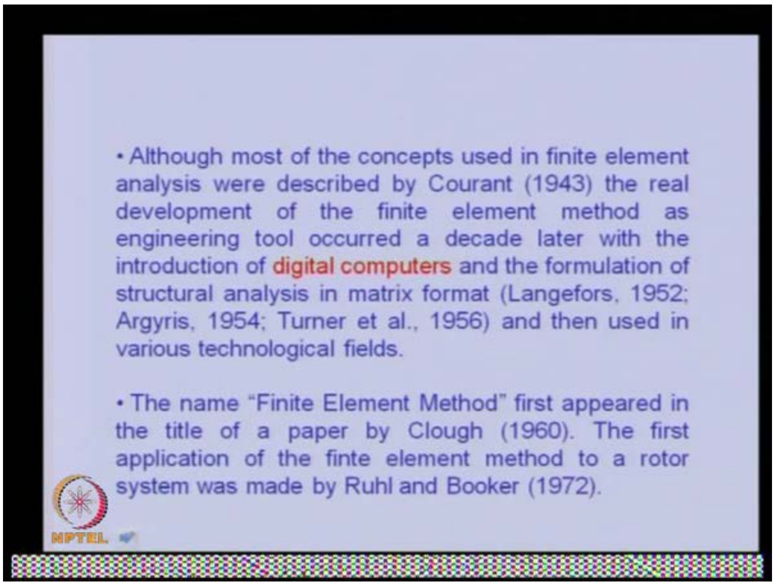

Although most of the concept used in the finite element analysis were described by Courant in 1943. The real development of finite element as engineering tool called in a decade letter with a introduction of visible computers and the formulation of structural analysis matrix format. Various researches and then used in various technological fields. The main finite element method, first appeared in the title of a paper by Clough in 1960. The first application of finite element method to the rotor was made by Rule and Booker in 1972.

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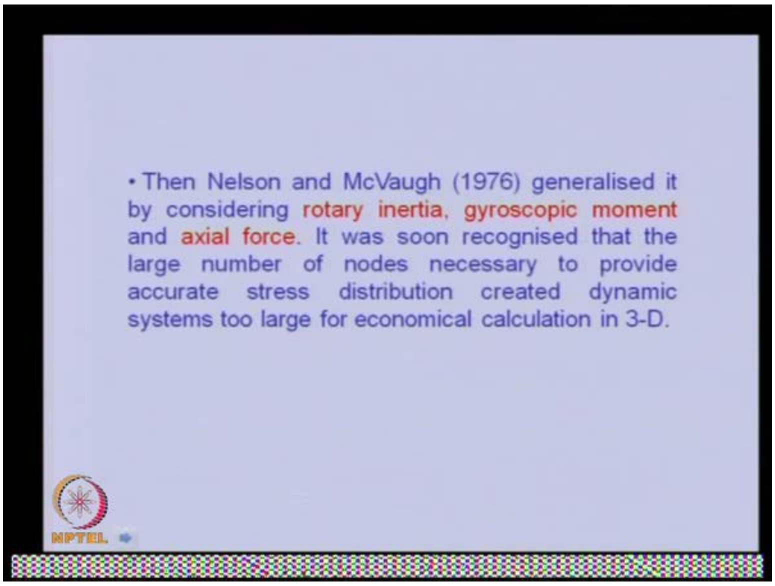

Then Nelson and McVaugh in 1976 generalized it by considering rotor inertia, gyroscopic movement and axial force. It was soon recognized that the large number of notes need to provide accurately stress distribution created dynamic system to large for economical calculation in three dimension solid model of structure rotor. Now, we will see how people they were balancing the rotor, then how the sophisticated method of balancing of such rotors based on the vibration took place in the history.

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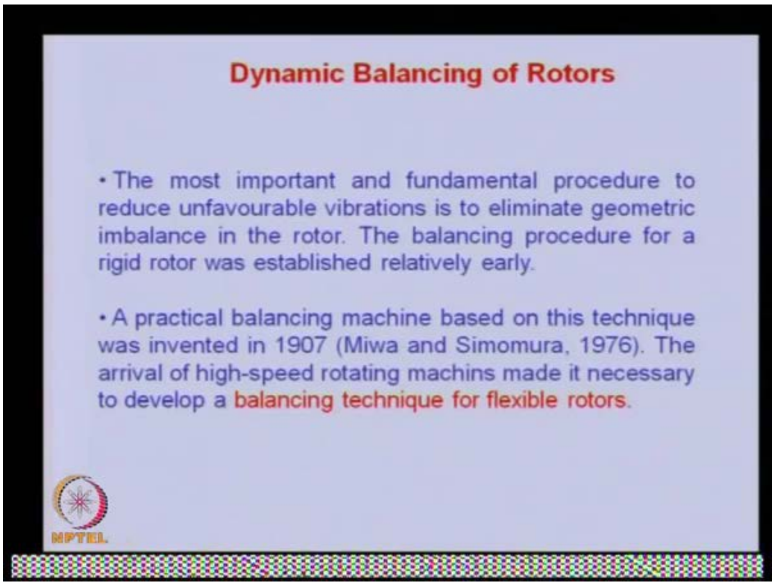

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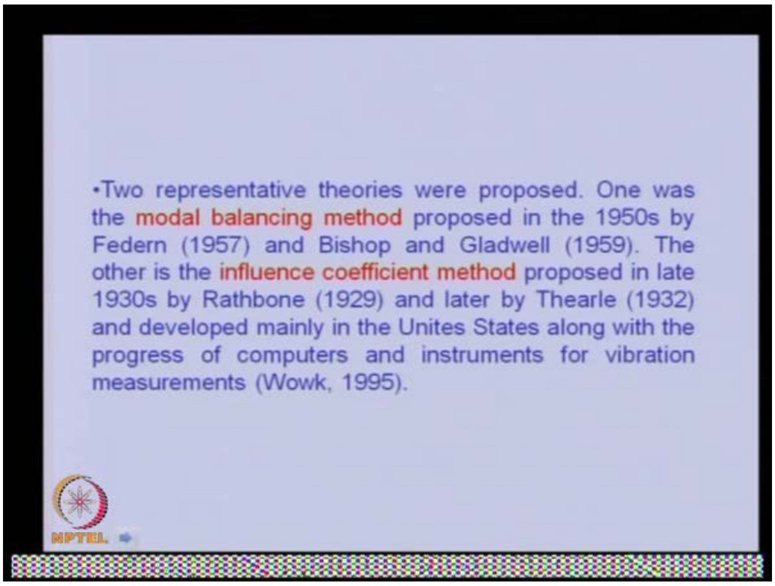

The most important fundamental courses to reduce unstable vibration is liberate geometric imbalance in the rotor. The balancing region of the rotor is relatively early, the particle balancing machine based on this technique was invented in 1907. The arrival of high speed rotating machine made it necessary to develop a balancing technique of flexible rotor.

Two representative theory were proposed, one was modal balancing method in 1950 by Federen Bishop and Gladwell. The other is the influence coefficient method opposed in late 1930 by Rathbone and later by Thearle in 1932 developed mainly in United States along with the progress of computer and instrument for vibration measurements.

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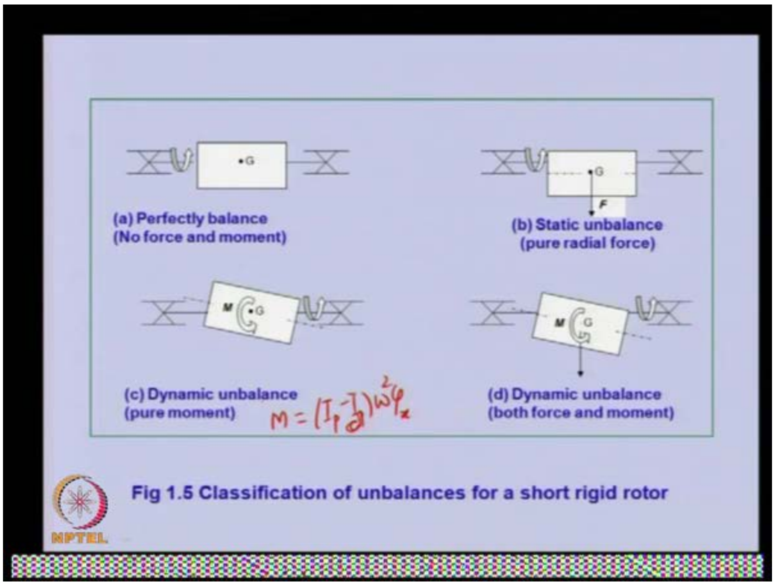

This is the basic concept of the rotor unbalance and the long rotor you can able to see the first is the perfectly balanced rotor. The geometrical centre of gravity in aniline with the centre of axis of the rotation of the shaft, first figure, second figure, there is static imbalance. That means there is a radial aspect of the rotor from its centre of rotation. So, because of this there is unbalance of force, second one is the long rotor and because of this there is a couple which acts.

The magnitude of this couple is acutely can be given as this is the angel of the till of the rotor obileded distance, speed, polar mass id, second word is the diameter and the fourth case is combination of the movement. The force is due to not only the dilating of the rotor, also due to radial sheet of the rotor. So, this will reduce both at the movement and you can the case b, single print balance, but k c and d 2 into balance.

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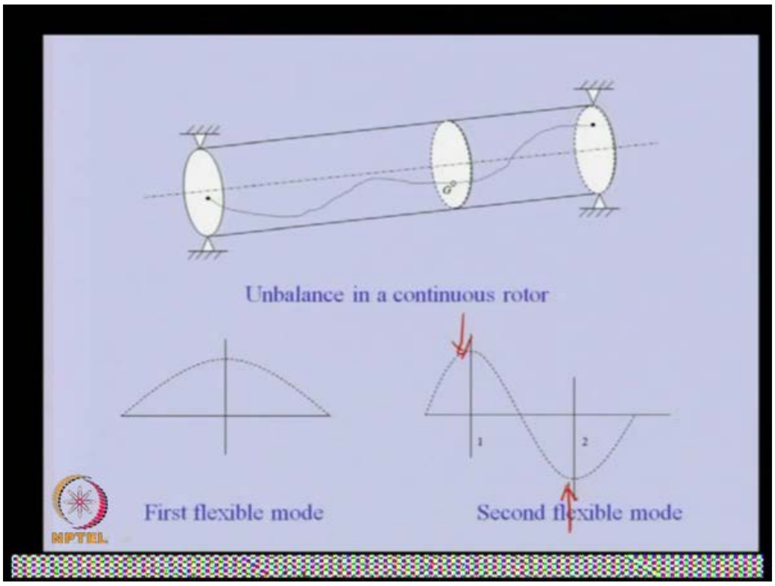

This is the rotor with long rotor, but it is a flexible rotor, you can able to see in general the axintesity will be varied readily. Also along with the annual and in this particular figure the central gravity executed just to demolistrate that and it can varied like this. But it will be the axintisity will be the order of microns and you can able to appreciate that the first one is the and the shaft is near the first critical speed.

So, half sign way, so we can able to balance this by single plate at mid span, but when we are operating with second mode. So, is full sign way and we require two plane to buy so that we can able to apply force on one in this direction. One in this direction so that this displacement of the rotor can be minimized and same you can able to see more number of modes.

So, that many number of planes will be there and you have to balance the rotor. Now, we will see some of the tools because the method which we are applying to analyze the rotors simultaneously, the development of computers were taking place. So, it will developing software’s for analyzing the rotors and these software indigenous software then gradually became the of the software is commercial one. So, let us see the substituent.

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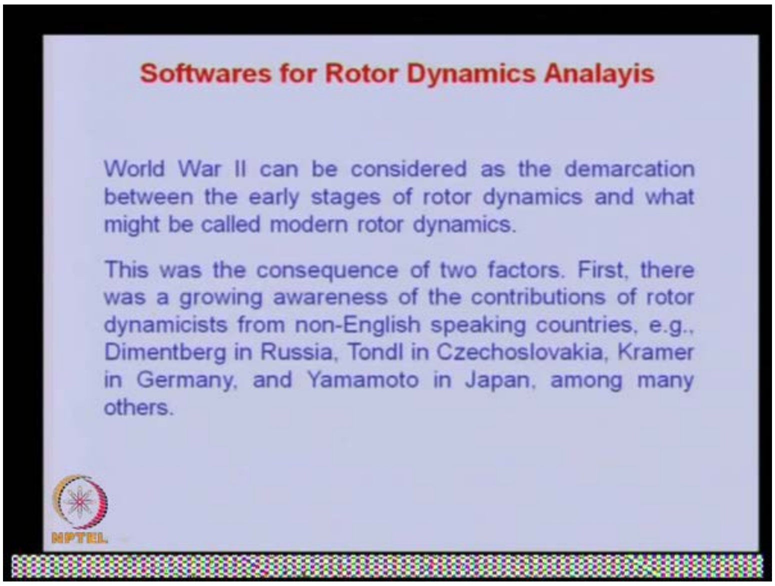

So, the world war second can be consider as demarcation between the early stage of rotor damping and what might be called as the rotor dynamics. This was the consequence of two factors, first there was a growing awareness of the contribution of rotor dynamics. Non English speaking countries like Dimertberg in Russia, Tondi in Czechoslovakia, Kramer in Germany and Yamamoto in Japan among many others.

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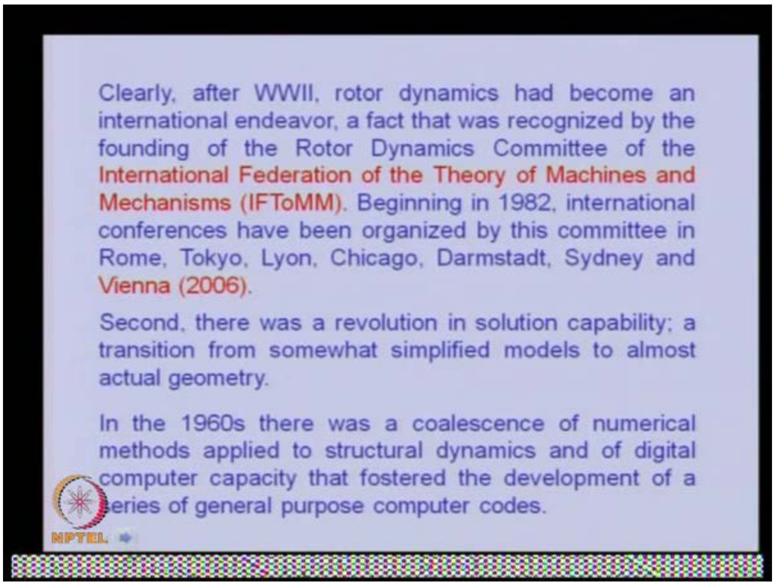

Clearly after the world war 2 rotor dynamics had become the international evader, a fact that was recognized with the founding of the rotor dynamic of the international federation of theory and machine and mechanisms. That is called IFToMM beginning in 1982. International conference had been organized by committee in Rome, Tokyo, Lyon, Chicago, Darmstadt, Sydney and Vienna in 2006.

Second, there was a revolution in solution capability, a transgression form for simplified method for almost actual geometry in 1960s. There was the collection of various numerical method, try to structural dynamics and digital computer capacity and faster the development. These are the annual computer course in this particular field.

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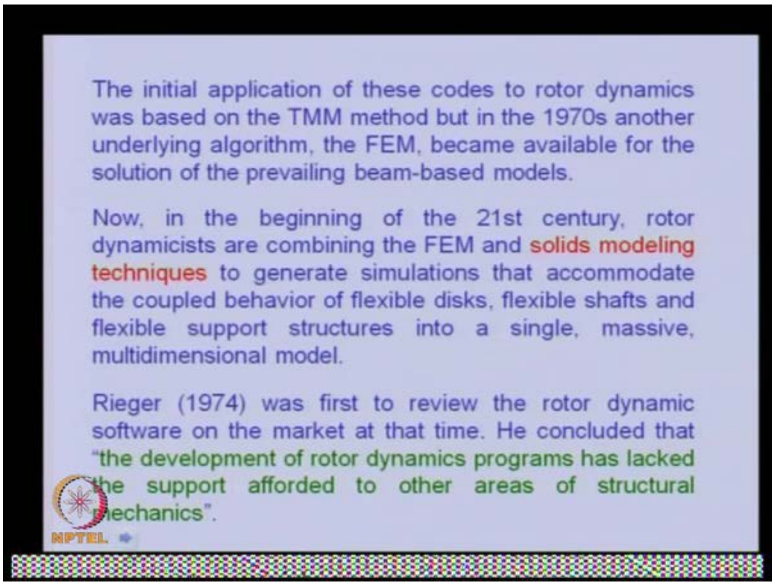

The initial application of this course, the rotor dynamics was on the transverse matrix compound, but in 1970s another underlying algorithm, the fem affiant became available for the beam based models. Now, in the beginning the rotor dynamics are mining solid generates simulation that accommodate the coupled behavior of flexible disks, flexible shaft and flexible support structure into single massive diversion of the model. Reiger in 1974 was the first to review the rotor dynamics and that time we conclude that programs support affront to other area to other dynamics.

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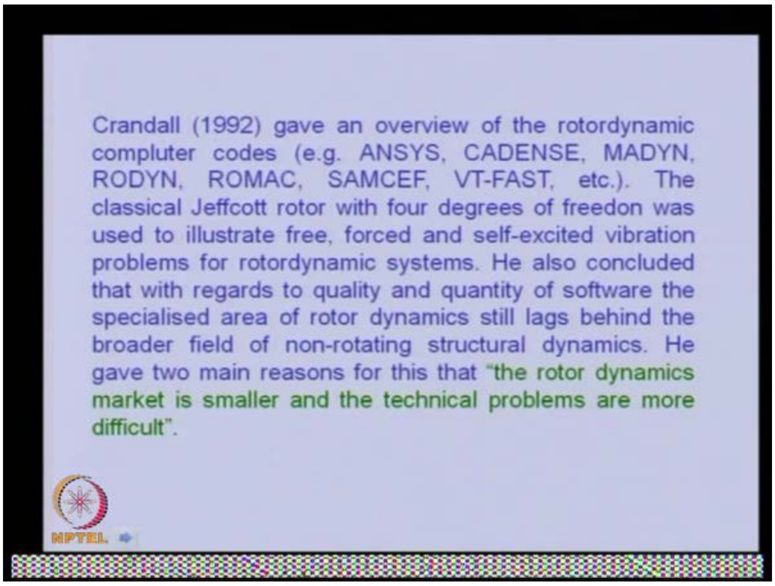

Crandall in 1982 gave an overview of the rotor dynamic course like Ansys and other software's available in the market. The classical Jeffcott total four degree was used to illustrate and self-exerted problems for rotor dynamic system. He also concluded that about the quality and quantity of the software, the specialized are of the dynamics still like behind the brooder field of non-structural dynamics. He gave two main reasons for this, that rotor dynamics market is small and the technical problems are more.

Now, I will review important aspect of such that is condition monitoring, because now whatever the theory of development of analysis rotor or the rotating machine are well developed and various rotating machine are operating in the industry. But during operation frequent fells are occurring, because of that this condition technique are getting more popular, so that both the money and power can be saved.

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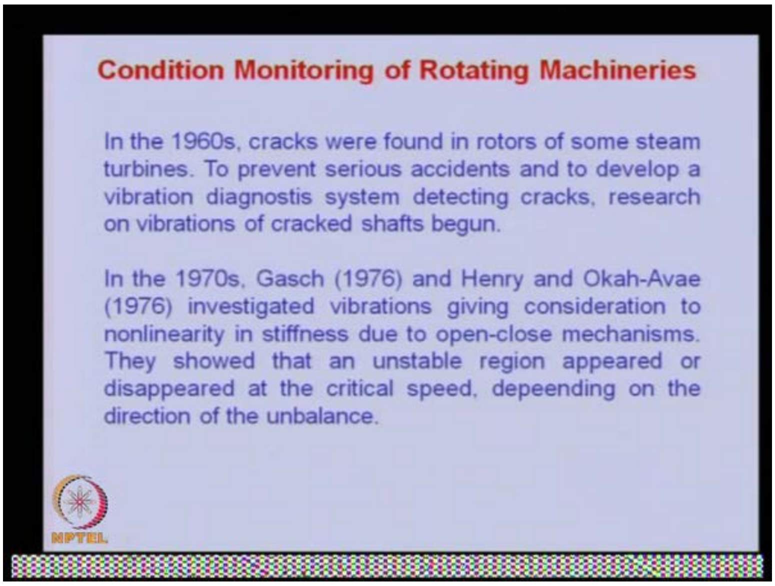

So, in 1960 we are found in rotors of same steam turbine to prevent serious accidents and to develop a vibration diagnosis system. Detecting research in vibration crate shaft begin in 1970s and in 1976, Hanry and other vibration consideration to non-linearity stiffness. Due to open close mechanisms, they showed that unstable region appear and disappear on the critical speed depending upon the imbalance.

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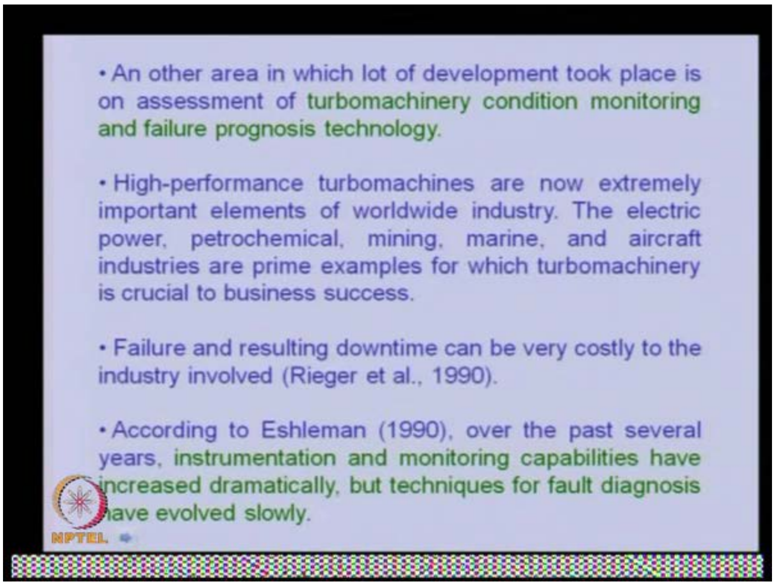

Another area in which lot of development took place is on the assessment of turbo machineries condition monitoring and failure technique. In this particular monitoring there are different level of addition monitoring possible, first is the detection of monitor, second is the diagnosis of these people try to find out what is the stimulate of the fault. Then the next stability is after finding the stability table, whether we can able to countrified a what is the life of the machine at that fault.

That means whether we can able to remaining life of the machine so that either we can able to operate the machine for few months, for few hours and we can plan the maintained or there is a urgencies or there is a some kind of a repeating this. There are different level of condition monitoring which we can able to do. This is the detection of the fault which we detect the fault and second stage is localizing. The fault in that we try to find out what is the fault of the machineries. Third stage is in which we tried to quantify the fault, that means that particular fault is having how much similarity and the fourth stage is in which we can able to find out how much time more we can operate the machine with that particular fault.

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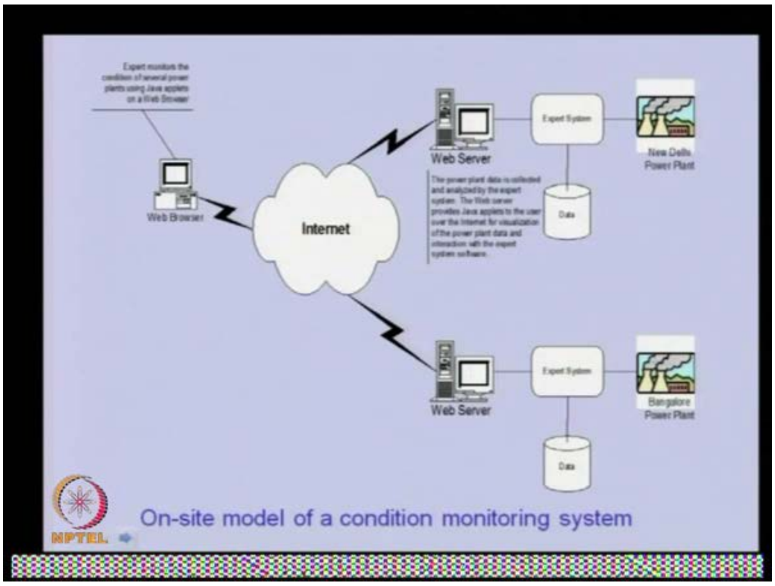

So, that is the useful remaining of the machine we can able to. So, that we can plan the maintains accordingly. So, high performance stationary, now extremely important element in the world wide industries, the electric power petro chemical mining and air craft industries are fine example for which turbo crucial for business success failure and resulting down time can be very costly to the industry involved. According to over the past several years sustentation and monitoring have increased dramatically, but the technique for fault diagnosis have been evolved slowly.

So, this is the typical mooned that is condition mooned, that is one side condition mooned in which we can able to see the power plant here. There is a various kind of information regarding this can be sent to expert system which will be storing data, may be the present data and the history of the plant. That can be sent to the server through internet to remote web browser where the expert can see the condition of the machine through analysis. This power plant can be different places and at central place some expected can analyze this particular data.

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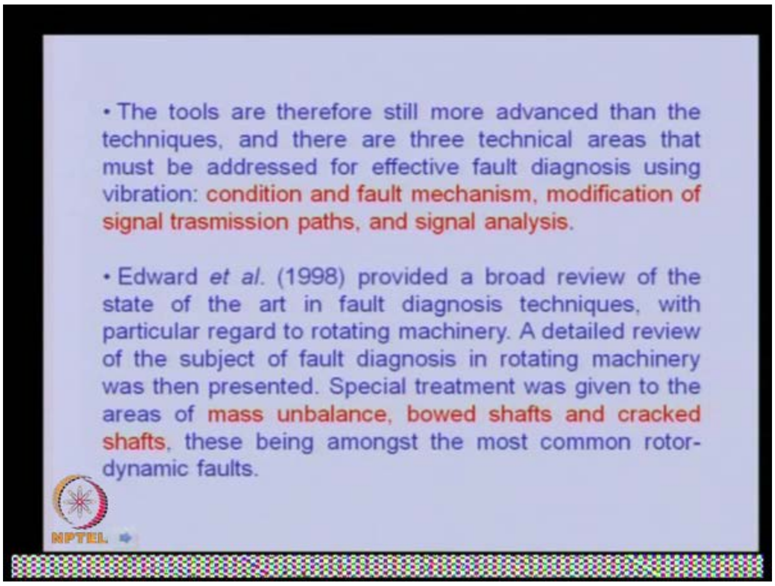

So, the tools are therefore still more advance than the techniques, and there are three technical area that must address or effective flow diagnosis using vibrations. There is condition and fault divagation modification of single transition path and signal analyses adware. In 1957 broad review of the state diagnosis with particular resort to the rotator, the detail review of subject rotating machine was represented. Special presentation was given to the area of mass imbalance board shaft, crank shaft, this being amongst the most common rotor dynamic fault.

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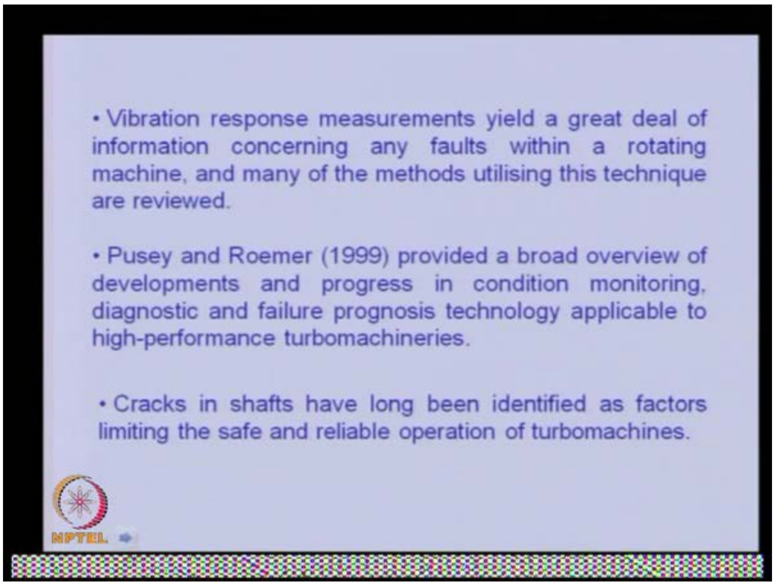

Vibration response measurement yield of information consenting any fault within a rotating machine, many of these method utilizes use this technique that are reviewed. In the particular paper, some other review are provided by the overview from the development and progress which are monitoring, diagnostic and failure prognosis is technique applicable to high performance progression craft in shaft have long been identified as factors limiting the safe and reliable operation of turbo machines.

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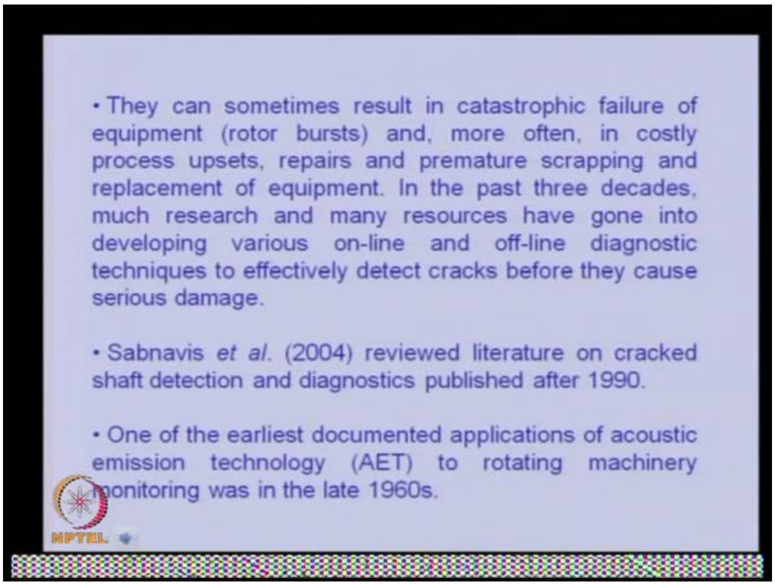

They can sometimes result in catastrophic failure of equipment rotor burst and more often in costly process, upsets, repairs and premature scrapping and replacement of equipment. In the past three decades much research and many resources have gone into developing various on-line and off-line diagnostic techniques to effectively detects cracks before they cause serious damage. Sabnavis in 2004 reviewed literature on cracked shaft detection and diagnostics published after 1990. One of the earliest documented applications of acoustic emission technology to rotating machinery monitoring was in late 1960's.

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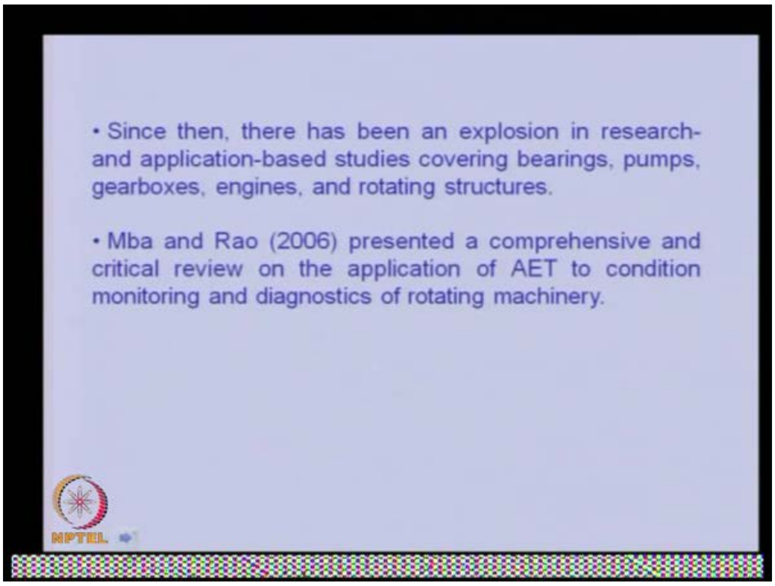

Since then, there has been an explosion in research and application based studies covering bearings, pumps, gearboxes, engines, and rotating structures. Some other researchers like MBA and Rao in 2006 presented a comprehensive and critical review on the application of AET to condition monitoring and diagnostics of rotating machinery. Now, we have already review analysis tool and condition monitoring tool and let us see trained in this particular topic of rotor dynamics, so that newly researches can see what is the openings in the research in the rotor dynamic field.

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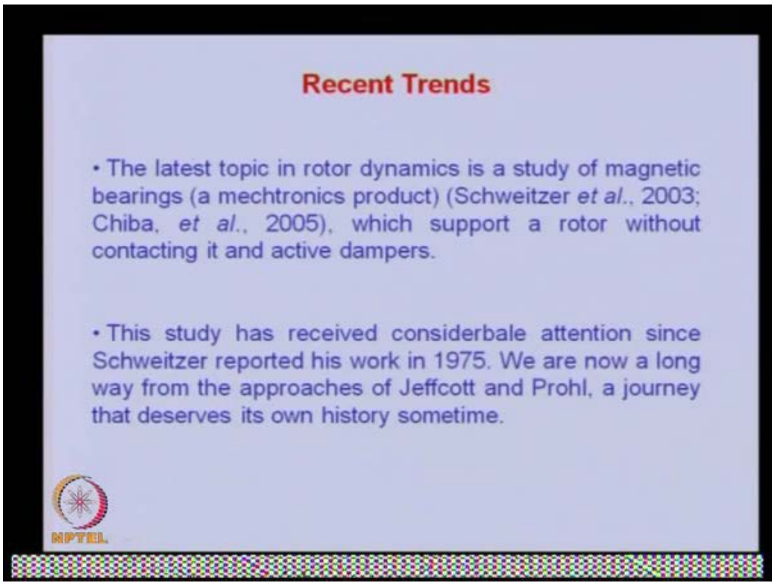

So, the latest topic in the rotor dynamic is the study of the magnetite bearing is a mechtronics product and which supports the rotor without contacting it and active damp fluids damping effect. This study was reviewed considerable attention since the work reported in 1975. We are now long from the approaches of Jeffcott and Prohl, a journey that deserves its own history sometimes.

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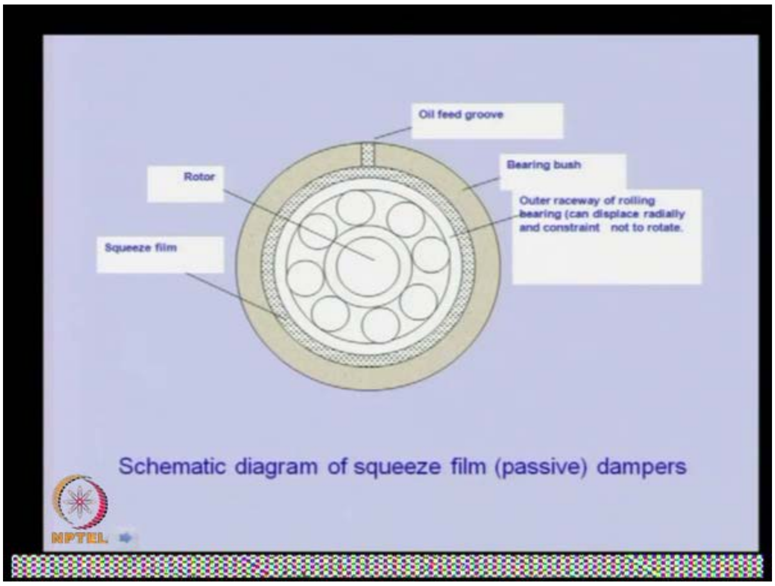

So, this is one bearing, actually this is squeeze filmed damper. This is damper, we can able to see inside is a some kind of the rolling element bead. The shaft is attached to the inner ratio of the bearing, these are rolling elements and then here it is a outer ring. And this outer ring and there a another casing here. In this there is fluid cavity, so as such is not out ring, only the inner ring and during motion up and horizontal and vertical direction. The fluid there between this is squeezed and that will provide damping. So, this is because the outer ring are rotating, so hydro dynamic action will not take place, only the squeezing action will take place. This is generally used in dampers of the resonance in the rotors to provide more damping in the system.

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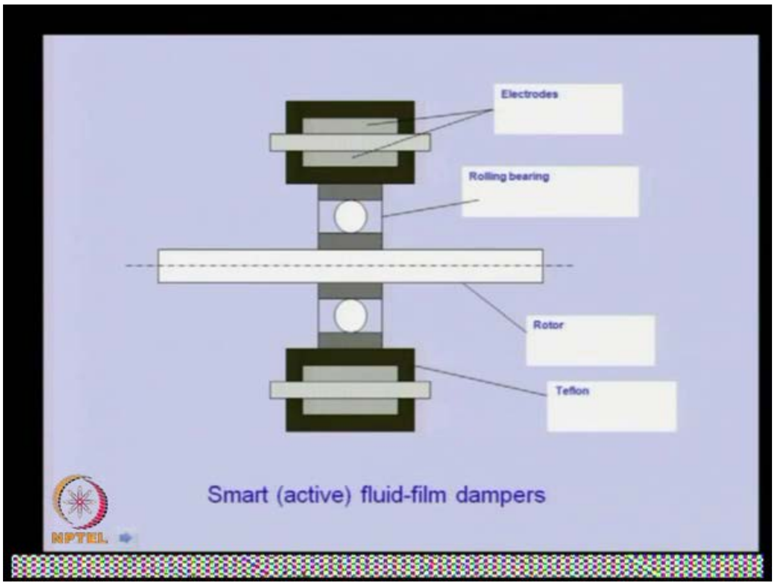

Now, let us see some active fluid filled dampers where you can able to see this rotor. This is bearing and here active device is there in which similar to this fluid damper, but everything is whatever the fluid is there. The property of that is getting change because of this electro, those fluids are special kind of fluid, either they are biological fluid in the form of magnet, logical fluid, and that we change this electros. The proper way of like stiffness damping changes and it gives different damping to the support system and this can be changed.

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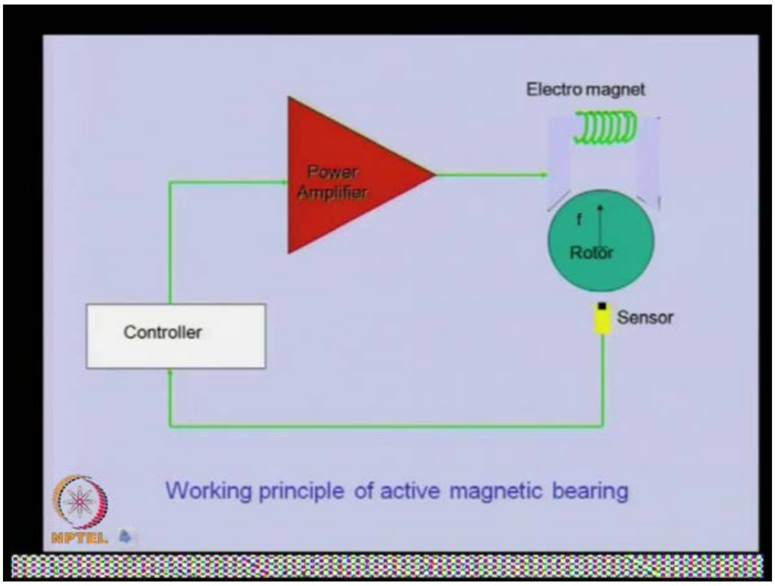

This is a magnetic bearing active magnetic bearing, this is rotor which is floating on air. The sensor measure it is vibration and it gives to the controller. Controller gives the acquired current to the and this amplifier gives the current. This actuator, so that required current can be given to the active vector and this will produce magnetic field to pull the rotor up and down, depending upon its motion. So, this is actually active magnetic bearing.

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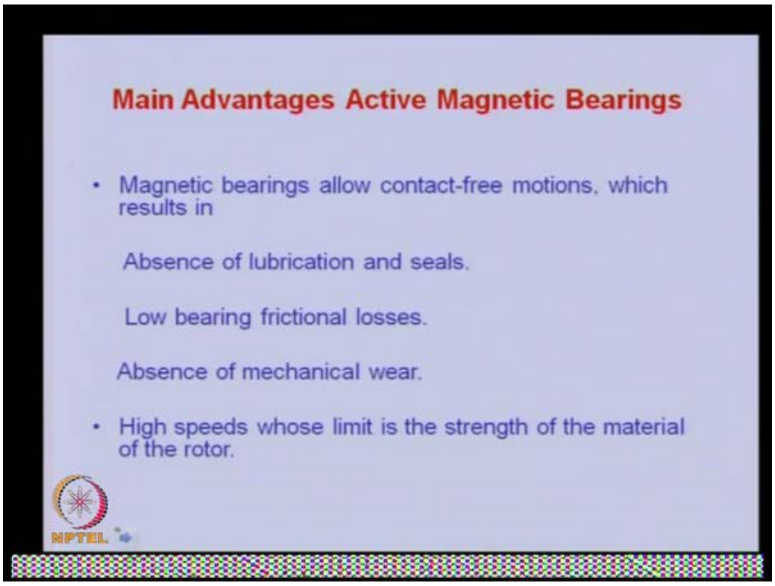

So, this is one of research area which is reactive we know the advantage of this bearing, that because the rotor flows on the air. So, there is no lubrication and friction is less. There is no mechanical and generally only the high speed whose limit is the strength of the material. There is no problem in the, such speed constant by the this particular bearings frictions on the rotors strength should be enough to have that much speed.

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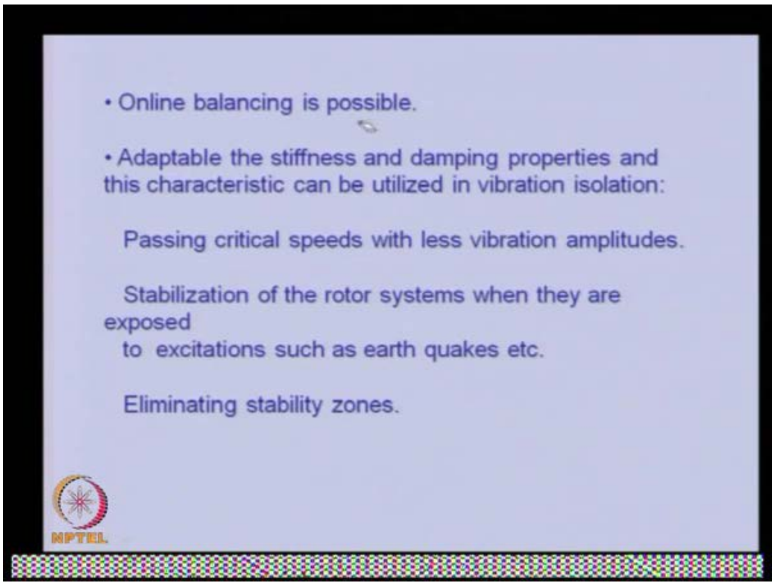

With this magnetic bearing, not only we can suppress the redolence only, also we can able to have a online balancing because we can adaptable the stiffness and damping property online. And this are the some other advantage like we can able to eliminating stability this is some, also in last two lectures we are see introduction to the rotor dynamics. We are seen in the history of rotor dynamics, even in the state of the art in the rotor dynamics brief to these lectures.

Specially, what is the resistance that is very important as I already mentions that one of the area where we should focus. That is the bearings, because bearings are still they are not those models are not capable or predicting actual behavior in the bearing, switching in there in the steam and most of the keys bearing use in equaling. Their property is they are hard to fine available to attain models or if practical's models are there. The difficulty is getting the proper property which this models requires, this difficulty in that.

So, more research is requires to a bearings, also we the foundation of the such rotors are very important. They also play role in dynamics of the rotor, apart from this in the bearing we are seeing some kind of acting bearing has come up. They still requires research so that they can be more able. Apart from this we have where is a phenomena which are non-linear phenomena in the rotor dynamics and that still requires more investigation, because several people has a study, mainly the linear analysis in the rotor system. With this I conclude particular lecture. In the lecture we see some very basic analytical models and analysis of the rotor dynamics. Now, in the long rotor case I will show another case in which.

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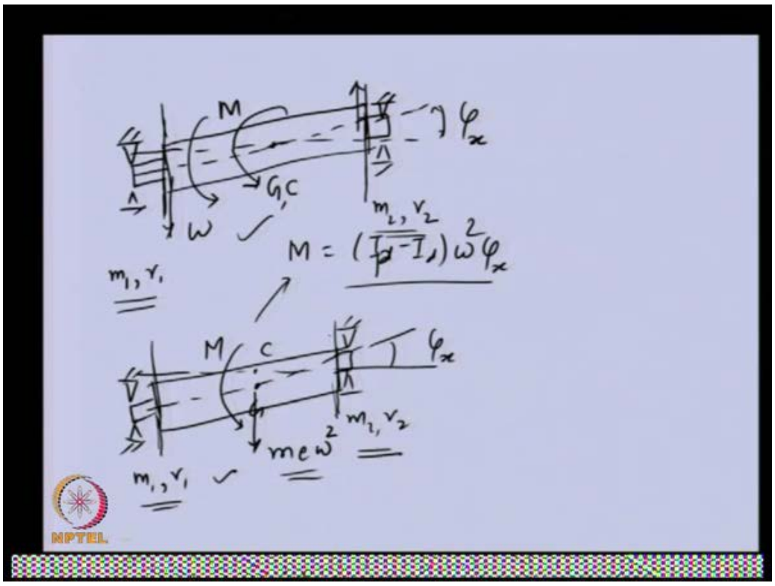

Let us say this the original axis of the bearing and shaft tasks is incline by a shaft term angle producing this angle is. So, the rotor is basically inclined, divide this and execarute the inclination just to show this particular incretion in this the center of gravity is there on the bearing axis.

So, geometrical and centrically at the same place, so this particular is the rotating with some option there will not be any center force. There was center rotation and center gravity and the same location, but there will be moment because of the inclination and that particular moment will be I p minus I d mega square. The angle of the rotor axis with respect to the bearing axis and for this particular case, because now moment is acting on to the rotor require to place to balance this particular rotor. May be kind able to chose one this hand, one this hand and you can able to either put some molecules and particular reduce and another mass at some other particular reduces to balance this particular moment.

Once we have this particular moment value and so this can be obtain using moment balanced in this particular plate and another case is where we have let us say here is a bearing axis and rotor axis case, not only incline but having some upset middle up set. So, this particular case you can able to see that the rotor will be having this are the rotor will be having force which will be M p omega square and deriving moment which will be same as the previous fund, the cause of the belt of the rotor.

In this particular case we have a both moment and the force and when we try to balance this particular rotor and this two locations will be having two different mass, different radial position. They can be used to balanced both forces and moment. So, both the cases the previous cases and this case will require only two plates to balanced the rotor and this particular kind of dynamics. In this called dynamics balancing and there was rotor was rigid. So, that why we require only to place to balance. In subsequent lecture we will try to derive these relations when we will cover the dynamic balancing of the rotor.