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## TECHNOLOGY OVERVIEW: SHOCK PULSE METHOD

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**Abstract:** The name, SPM, is derived from the technology that SPM Instrument developed and patented in the early 70's in Sweden. The Shock Pulse Method is the monitoring and analyzation of high frequency compression (shock) waves generated by a bearing while rotating. From this research, empirical data was developed and patented to measure the theoretical film thickness of the lubricant in a rotating bearing along with an analysis of the overall condition of the bearing surfaces.

The way these signals are separated is really what makes this technology unique. Unlike vibration analysis that monitors a broad vibration band and then tries to isolate unique frequencies; SPM has developed a means to only "look" at the high frequency signals of antifriction bearings. Having ensured that the signal quality truly reflects a bearing signal, the development of a defined data base by SPM became practical. The ability to analyze lubrication changes versus surface damage becomes more practical and repeatable.

Through years of testing, this data base has been developed and perfected so as to represent the "True" operating condition of the bearing being monitored. Regardless of whether the bearing is 5 days old or 5 years old the reading taken represents the operating condition at that time.

**Key Words:** Code; condition; decibel; kilohertz; lub; pulse; resonant; shock

Condition monitoring means different things to different people. When you look at the most common problems of rotating equipment, the bearing condition is of most concern. With over 20 years of worldwide experience, SPM certainly finds this to be true. (Fig.1)

When one looks at what is conventionally used for machine analysis we see a vibration time signal. Ninety nine per cent of that signal is affected by rotational forces, which is helpful for problems that exhibit repetitive signals and therefore show up at discrete frequencies. The difficulty in monitoring antifriction bearing signals along with the other rotational forces is that the vast majority of bearing damage is not a repetitive signal and hence not always found at a discrete frequency. (Fig.2)

Shock pulses consist of a string of pulses with varying magnitudes. The strength of the individual pulses, and the ratio between stronger and weaker in the overall pattern, provide the raw data for

bearing condition analysis. The magnitudes of these pulses are dependent on the bearing surface condition and the peripheral velocity of the bearing (rpm and diameter). In undamaged bearings, the shock level varies with the thickness of the lubricant film between the rolling elements and raceway. The relationship between stronger and weaker pulses, however, is hardly effected. Surface damage causes an increase of up to 1000 times in shock pulse strength, combined with a marked change in the ratio between stronger and weaker pulses. Shock pulse values are translated into measurements of oil film thickness or surface damage, whichever applies. (Fig.3)

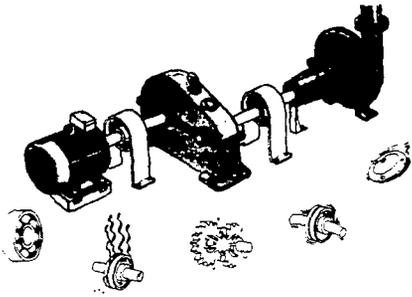
Only a small percentage of bearings fail because the natural fatigue limit of the bearing steel has been reached. For the large majority of bearings, metal fatigue starts early because the rolling elements and raceways are not properly separated by a protective lubricant film. The cause of this is often insufficient or incorrect lubrication. Improper mounting, dirt in the bearing, electrical currents, and machine vibration also cause reduced bearing life.

In a given bearing application, a number of factors that influence the lubricant film are constant. These factors include static and dynamic load; the geometry of the bearing housing, shaft and bearing; rolling velocity and necessary pre-load. Other factors can be influenced by maintenance personnel, making it possible to have a significant impact on bearing condition and life. These factors include pre-load (due to incorrect mounting), shaft alignment, total load (by correcting alignment and pre-loading), lubricant supply to the bearing, lubricant type and lubricant quality. Bearing temperature depends on constant factors such as velocity and environment, as well as lubrication. (Fig.4)

The  $L_{10}$  value is the life expectancy stated by the bearing manufacturers, representing the time it takes for 10% of the bearings to fail. Bearing life is also a function of the bearing's lambda value, which is the ratio of the oil film thickness to the surface roughness. A value of approximately 1.2 is generally needed to reach  $L_{10}$  life. In ball bearings that have less surface roughness than roller bearings, a LUB No. of 3 corresponds to  $\Lambda = 1.2$  and thus to 100% of the projected bearing  $L_{10}$  life. In roller bearings, which have rougher surfaces, the corresponding LUB No. is 6. The SPM curves show the relationship between LUB No. and the  $L_{10}$  life for roller bearings (upper) and ball bearings (lower). The SPM LUB No. is a measurement of a relative oil film thickness. When the lubricant film in the measured bearing is thin, the shock pulse meter will indicate a low LUB No. Checking and, if possible, improving the lubricant supply is often the easiest remedy and the first remedy that should be tried to improve operating condition. Operating with an insufficient LUB No., a bearing will in time develop irreversible surface damage. The reality is, while bearing manufacturers have defined bearing  $L_{10}$  life, few applications can achieve the lubrication level necessary to meet that life. The Shock Pulse Method allows the user to maximize the LUB No. to whatever the bearing can sustain under its operating conditions (RPM, Load, Temperature). "True" Condition Monitoring will allow the end user to obtain actual lubrication condition the first time a reading is taken and not rely on the user to develop the data base. (Fig.5)

Extensive research was undertaken to establish the relationship between the shock pulse signal from a bearing and its lubrication condition. An examination was made of a large number of bearings of different sizes and types. Variables examined include rpm, load, as well as lubricant

# Condition monitoring



Typical mechanical problems

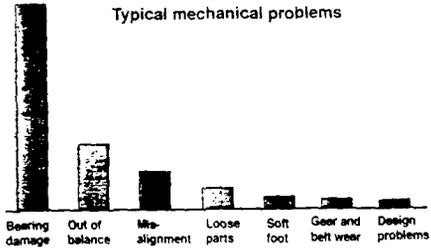


Fig 1

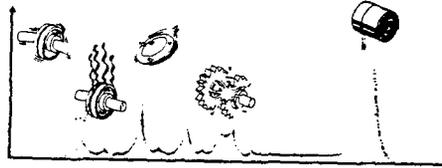
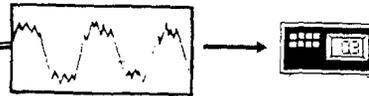
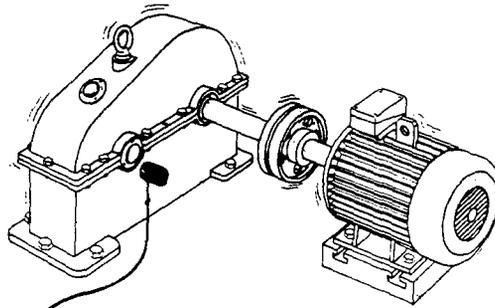


Fig 2

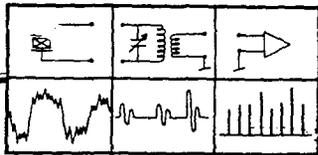
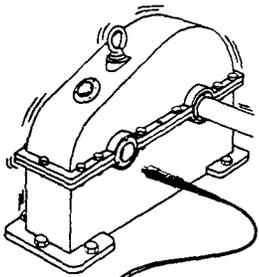


Fig 3

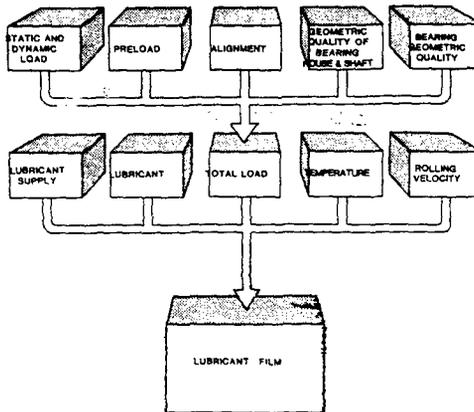


Fig 4

temperature, quality and supply. Measurements taken included shock pulse intensity(decibel) and pattern, bearing temperature, and the amount of electrical contact through the bearing. Shock pulse measurements were initially collected from all types and sizes of ball and roller bearings lubricated with kerosene and then loaded. No interruption occurred in the electrical contact through the bearings. These readings, representing the bearing's shock levels under dry running conditions. When subtracted from their shock measurements obtained from lubricated bearings, the difference in shock value, delta dB, was related to the time of no current flow. The dB difference values were mathematically converted into units for measuring oil film thickness (LUB No. ). The scale was selected so that one unit of LUB No. change is approximately one micro inch change in oil film thickness. (Fig.6)

A shock pulse transducer contains a reference mass (m) and responds with a dampened oscillation when hit by a shock wave, here produced by hitting the transducer with a screw driver. Attached to the reference mass is a piezoelectric crystal that produces a voltage when compressed by the movement of the reference mass. This voltage is proportional to the amplitude of the oscillation and thus to the energy of the shock wave. The principle is somewhat similar to the one used in the accelerometers for vibration measurement. Shock pulse transducers, however, are mechanically and electrically tuned to operate at their resonance frequency of 32 KHz ( $f_m$ ) where the resulting bearing signal is strongest. This provides a very sensitive transducer with a very favorable signal-to-noise ratio. (Fig.7)

At the moment of impact between two colliding bodies, a pressure wave spreads through the material of both bodies. When the wave front hits the shock pulse transducer, it will cause a dampened oscillation of its reference mass (m). The peak amplitude (A) is a function of the impact velocity (v) at the moment of impact. So for Shock Pulse Technology the mass of the objects is not a factor in the accuracy. During the next phase of the collision, both bodies will start to vibrate. The frequency of this vibration is a function of the mass of the colliding bodies. The initial pressure waves transient quickly dampens out. It causes the reference mass of the shock pulse transducer to vibrate at its own resonance frequency of 32 KHz. The resulting voltage is a function of the vibration amplitude and thus proportional to the impact voltage.(Fig.8)

Shock pulse analyzers measure signal strength in dB<sub>SV</sub> (decibel shock value) at two different levels. **HR** = High Rate of signal occurrence, the level at which 1000 shocks per second can be counted; and **LR** = Low Rate of signal occurrence, the level at which approximately 50 shocks per second can be counted. **HR**, **LR** and the difference between them (+dBsv), are used to evaluate the signal and determine the bearing's operating condition.

A microprocessor evaluates the signal. It needs input data defining bearing type and rolling speed. Rolling speed is calculated from rpm and mean diameter ( $D_m$ ), and input as an SPM NORM number. Bearing type (ball, roller, single and double roll) is input as the SPM TYPE, number 1 through 8. Bearing Condition is described by a letter code (A, B, C and D) and by a Green-Yellow-Red scale. CODE A(Green) means a good bearing, B(Yellow) means a good bearing with severe LUB problems, C(Yellow) is a bearing with early damage and D(Red) is more severe damage. The LUB (lubrication) number is the relative oil film thickness so whenever it is displayed a major goal would be to maximize it and then maintain that LUB number over

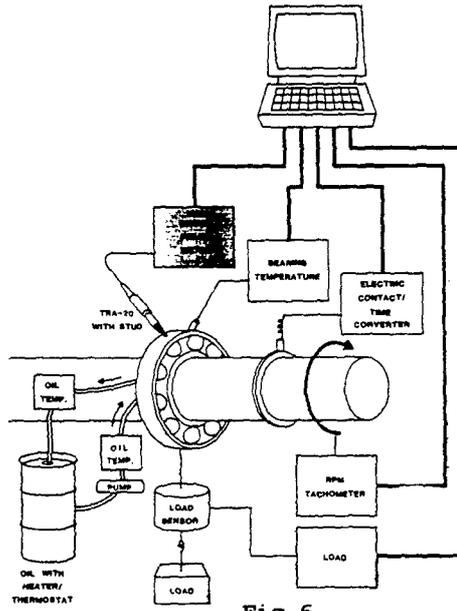
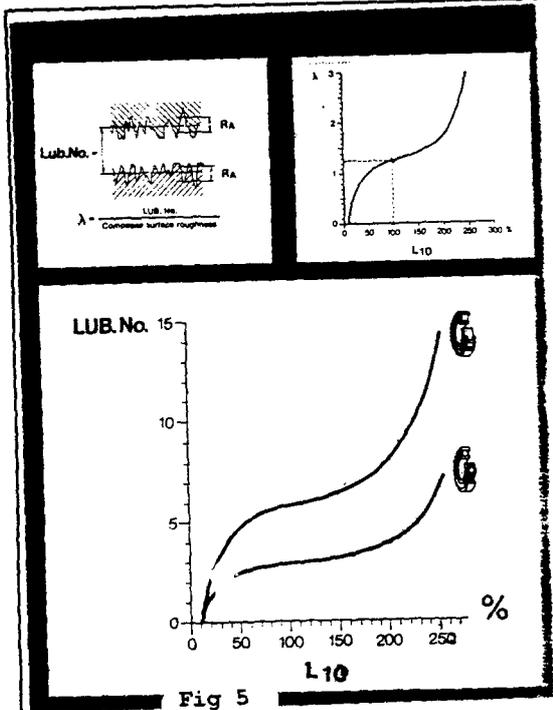


Fig 6

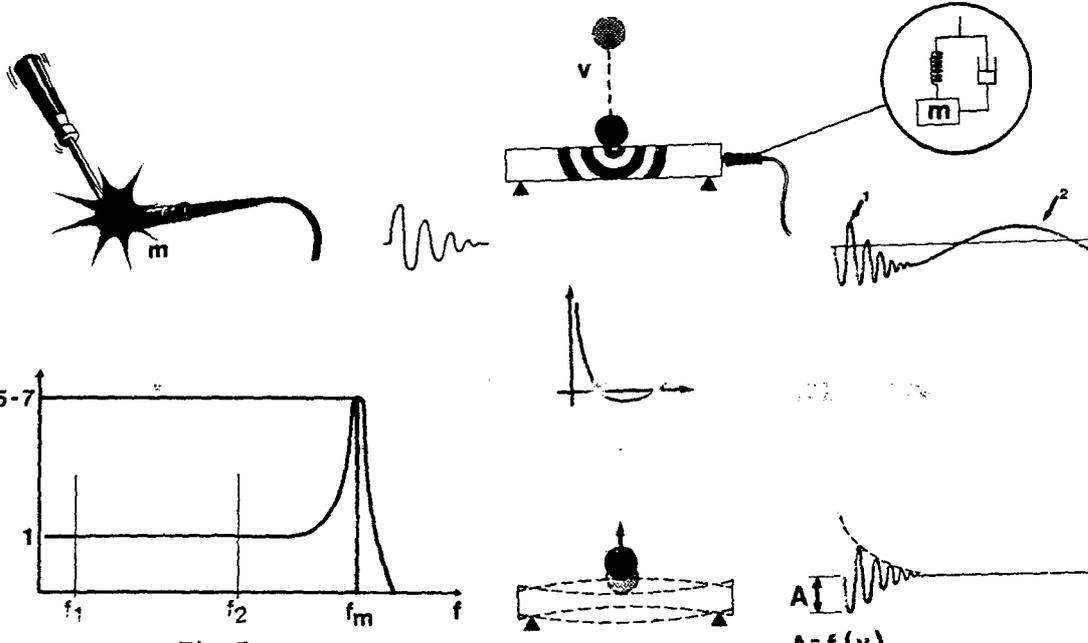


Fig 7

Fig 8

operating time. The COND (Condition) number indicates the degree of surface damage and once it appears it must be tracked so as to pick up increasing damage severity. As a result, "True Condition Monitoring" is available for bearings in both portable and continuous monitoring systems. (Fig.9)

Use machine specifications to identify the location of bearings and their construction. Measurement points should be selected and prepared with care to be sure that future readings are repeatable. Shock pulses are generated in the interface between the rolling element and the raceway, in the loaded part of the bearing. From the outer raceway, shock pulses are transferred to the bearing housing. To select a measurement point, the signal path must contain only one mechanical interface, that between the bearing and the bearing housing. The signal path between the bearing and the measurement point must be straight, solid, should be in the loaded region of the bearing housing. With the many bearing applications it is not always possible to meet these requirements and signal dampening occurs. In 1992 newly developed Shock Pulse Methodology eliminated this problem and now provides even greater accuracy for analysis. This dampening phenomenon actually has many causes. Low RPM, low load, housing material porosity are but a few causes. One quickly realizes that weakened signals are prevalent on most good bearings. Through advancements from SPM R & D, a bearing location can now be "initialized" and the analyzer will automatically calibrate the signal loss for a good bearing. This is accomplished by SPM patented empirical data calculating a compensation number corresponding to the degree of signal loss. When dampening is detected then the compensation number will provide a more accurate evaluation. This new technology is built into the all portable and continuous monitoring systems and in SPM LUBMASTER and CONDMASTER software. (Fig.10)

Automatic Bearing Evaluation is the basis of the Shock Pulse Method. With "True" SPM Condition Monitoring, the user need not collect multiple spectrums or have to evaluate them. The portable shock pulse analyzer or the continuous monitoring systems provide direct condition monitoring (e.g., "bearing severely damaged"); Green-Yellow-Red Condition Analysis. (Fig.9)

The major benefit of the Shock Pulse Method is providing a direct indication of bearing condition on a Green-Yellow-Red scale. A single reading can provide reliable values for oil film thickness and surface condition. This is very important when monitoring installed bearings on machines for which there are no trends or comparable readings. Performing Condition Monitoring includes making a decision on the type of maintenance required. With bearings, there are three common possibilities: 1) Satisfactory oil film, no surface damage, no special maintenance required; 2) Thin oil film and reduced life expectancy, the questions that must then be asked are: Can the oil film be improved? How can that be done? Is it worth the effort? and 3) Bearing damage, the bearing has to be replaced, the question is when. (Fig.11)

With the Shock Pulse Method a CODE Letter D normally indicates bearing damage. Surface damage is irreversible and will increase with time. Whenever verified readings show bearing damage, shorten the measuring interval and trend the Condition No. While it is not possible to say exactly when a damaged bearing will fail, as a guide: Condition No.'s > 45 infer a high risk for failure. Rapidly increasing Condition No.'s also mean a high failure risk. Both factors together should lead to an immediate shutdown and bearing replacement. (Fig.12)

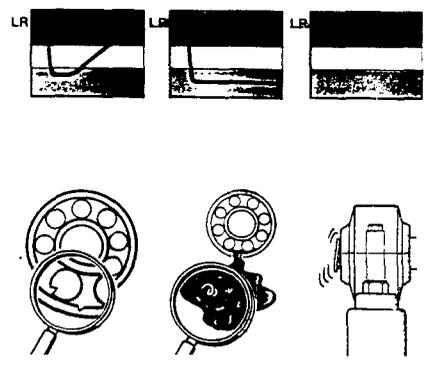
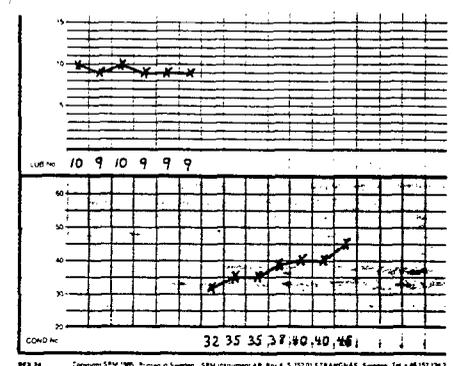
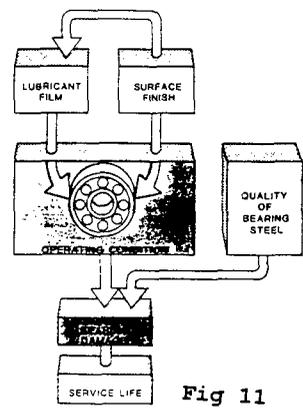
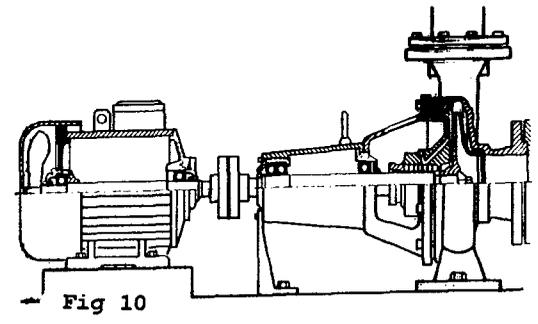
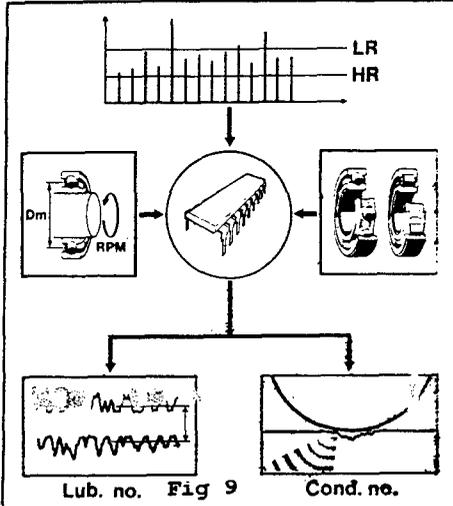
A lubrication test can be performed on bearings suspected of bearing damaged. To test grease lubricated bearings for possible causes of high shock values, relubricate with clean grease. Measure the LR before lubricating, then shortly after lubricating, and again a few hours later. If the shock pulse value drops, then rises again, the most likely cause is bearing damage. If the shock pulse value drops and remains low, the contaminated lubricant has been replaced by clean lubricant, with no bearing damage. Lubricate again to see if the LR drops farther. If it does not, then, record the LUB number. If it increases after relubrication then the bearing has been overlubed and the previous measured LUB number is the maximum the bearing can maintain. If the shock pulse values are not affected after lubrication, suspect the signal is mechanical in origin and the hydraulics of the lubricant can not overcome the mechanical forces. Look for misalignment in the drivetrain or in the bearing installation. We know the relative thickness of the lubricant film has a direct influence on bearing service life. In order to achieve better lambda ratios and hence longer service life, the relative film thickness must be maintained and increased when practical. Relative film thickness (as measured by the SPM LUB Number) is influenced by many factors. (Fig.13)

The CODE Letter A relates the measured film thickness to a calculated value that the bearing should have according to EHD lubrication theory. CODE Letter B shows that film thickness is less than it should be, and that improvements are possible. Similarly, decreasing LUB No.'s indicate a deterioration of the oil film. In reality, few bearings operate in an environment that allows it to reach a LUB number or a film thickness necessary for full rated bearing life. RPM, load, temperatures are some of the factors that could prevent this. With the SPM Shock Pulse Method you can at least see the Lubrication Condition immediately so as to try to maximize the LUB number to whatever value the application allows. With a maximized LUB number you now have a standard for a lubrication schedule. (Fig.14)

To improve lubricant film, it is necessary to understand the factors which influence film thickness. Obviously, a certain amount of lubricant has to reach the area of rolling contact in order to supply the film. The thinner the film, the higher the HR level signal (dBsv), measured in the bearing. (Fig.15)

In many cases a supply of fresh grease to the bearing will improve its LUB number or restore it to the previous level. This can have a dramatic effect on bearing life. As the graph shows, increasing the LUB number of a roller bearing from 2 to 8 can extend bearing life by a factor of 10, provided the surfaces were not already affected during the period of near dry running. It is therefore important to lubricate regularly and at optimum intervals, so that the oil film never becomes too thin. (Fig.16)

The Shock Pulse Method allows oil condition monitoring over the whole speed range, from low to high rpm. The development of film thickness with speed in this roller bearing goes through three distinct stages: (1) At LUB No.'s below 5 there is metallic contact between the surfaces in this bearing for NORM numbers below 30. The speed at which surface contact ceases differs with bearing type, but lies mostly between NORM numbers 30 and 40. In the low speed range, oil film thickness cannot become greater than the composite surface roughness. Hence the only chance to



S

BEARING TEST			
CODE	B	AGE	33
LUB	0	LR	24
COND	28	HR	23

CODE Letters A to D: grade of bearing condition  
 LUB Degree of lubrication or the testing material. Distinctive with CODE A, B  
 COND Degree of damage to bearing surfaces. Distinctive with CODE B, C, D

Fig. 14

CODE A Good condition

CODE B Dry running

CODE C Reduced condition

CODE D Bearing damage

Fig. 17

Fig 14

improve film thickness is by using a lubricant with higher viscosity. (2) The bearing surfaces are completely separated by an EHD film, which rapidly increases with speed. For bearings with NORM numbers between 30 and 50 it is normally easy to achieve good lubrication. (3) If speed is further increased, lubricant starvation could set in and oil film thickness tends to drop. The Shock Pulse Method can provide this lubrication condition without the user having to develop his own knowledge base. (Fig.17)

**Case Study #1-** Paper Mill in Oklahoma. Readings taken on 12 consecutive dryer can bearings. Bearings are spherical roller, P.N. 22138 at a speed of 75 RPM. On this particular demonstration a shock pulse analyzer was programmed with the physical information of the bearings and a 30 second reading was taken on each housing at the same location on each housing. The first readings taken show marginal LUB numbers on locations 1 through 4 and 9 through 12. Locations 5 through 8 showed good lubrication condition. In all cases, the Shock Pulse Method reported that all the bearings were in good condition and without damage, then it displays where there is room for improvement with lubrication. At first it was thought that the lubrication lines to these bearings might be blocked. This was quickly eliminated as a possibility when the maintenance manager expressed agreement with the meaning of the shock pulse readings. It seemed he had for years felt that the lubrication rate was inadequate for the rpm. A few years earlier, the machine speed had been increased with a corresponding increase in oil temperature and bearing failures. Increasing the oil flow rate was not possible because undersized oil return lines caused such an excessive back pressure that oil start leaking through the seals and the flow rate had to be cut back. He requested that the oil return lines be modified and a test area was chosen to include the lines for the middle bearings, 5 through 8. He would have to prove the value of this repiping by monitoring the bearing failure rate between the different locations. He had made the piping changes and then increased the oil flow but he had no method to determine if there was any improvement in the bearing condition. Now the SPM Lubrication Number provided that proof. He then wanted to see if there was further improvement possible so he increased the drop rate slightly on location #5 and the SPM Lubrication Number indicated further improvement. Still more increase in drip rate and the SPM readings reversed themselves-identifying over lubrication. By using the SPM Method the LUB Number or film thickness is optimized on each of the bearings and thereby the bearing life is improved. (Fig.18)

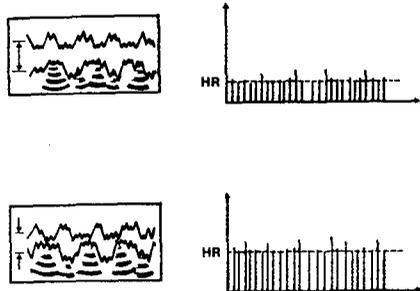


Fig 15

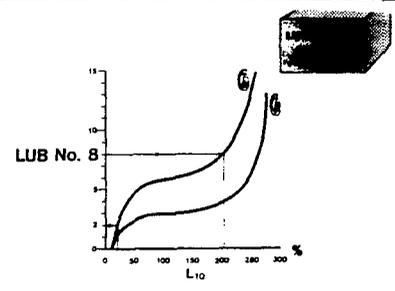


Fig 16

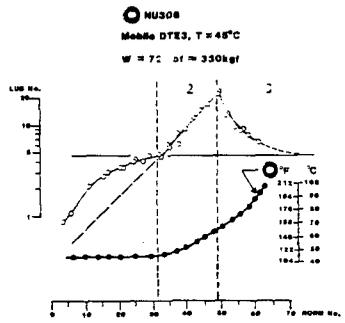
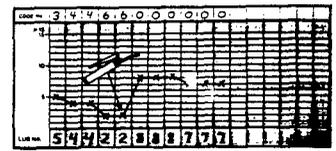


Fig 17

CASE HISTORY #1  
 Location: Paper Mill in Oklahoma. Monitoring 12 Dryer can bearings. Bearing Part number 22138 running at 75 RPM

LOC #	1	2	3	4	5	6	7	8	9	10	11	12
LR	11	10	10	10	2	1	2	1	12	11	10	11
HR	7	7	7	6	-3	-3	-2	-3	7	7	6	7
CODE	A	A	A	A	A	A	A	A	A	A	A	A
LUB	1	1	1	1	4	4	4	4	1	1	1	1

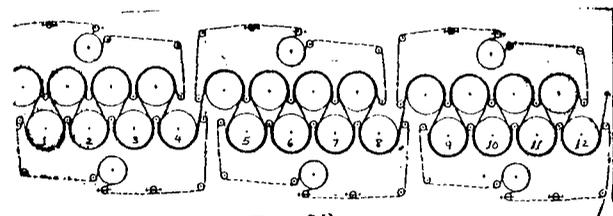


Fig 18