Importance of early detection of maintenance problems in rotating machines in management of plants: Case studies from wire and tyre plants

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A B S T R A C T

In this article, importance of application of predictive maintenance concept with vibration measurement has been discussed. Appreciation of the subject was performed with the help of data collected cases related to maintenance problems from Plants A and B. The first case was examined in aerial conductor manufacturing Plant A. The company does not apply predictive maintenance (PM) in management of the manufacturing activities. The machines used in conductor and similar wire processing plants have very big rotors and their loads on rotors continuously change. Therefore, these types of machines are good examples in checking the health of the machine regularly. The second case was analysed in vehicle tyre plant named as Plant B and it has perfect usage ability of vibration technique of PM methods. The importance of the regular collection of vibration signatures in evaluation of conditions of rotating machines has been analysed in details to indicate the power of the predictive maintenance technique in prevention of losses, which are caused by unbalanced forces, misalignments, improper lubrication of ball bearings, metal fatigue and cracks occurred in welding of constructed parts and locking of the ball bearings due to excessive heating.

The second case observed in Plant B is an example to show detection of a ball bearing failure just in time. Evaluation of second case has been performed using measurements of vibration signatures of the machines with the help of fault indicator graphics.

Results from the cases have been summarised to give useful ideas in management of the plants to the persons responsible with production and maintenance subjects.

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1. Introduction

Maintenance strategies are very important in management of the manufacturing process. In the organisation plan of the factories, manufacturing and sales departments are prime importance. Maintenance department is considered as consumer of income of company. It is thought generally that they present always a plan to stop production machines for maintenance aims. To decrease maintenance cost yearly, several strategies have been developed. However, most of them require huge budget to keep the machine in good condition. That is why; companies seek a maintenance technique to spend money just in time. The technique accepted by the most companies is the PM (predictive maintenance).

In our case studies, two companies have been considered. One of them is the "manufacturing plant of aluminium conductor and power cable" indicated here as Plant A. The other one is the "Automobile Tyre Production Plant" indicated here as Plant B. Plant A do not use predictive maintenance technique in the management of the process but Plant B uses it to follow the condition of machines regularly by collecting vibration data from the whole machines run in the production.

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The predictive maintenance by vibration analysis is the best tool for checking of the conditions of the machines regularly in the production activities. The vibration analysis is a technique, which is being used to track machine operating condition and trend deterioration in order to reduce maintenance cost and downtime simultaneously.

This technique consists of vibration measurement and its interpretation. Firstly, vibration signal are collected by means of vibration analyser equipped with sensor in the time domain then, these signals are converted into frequency domain by processing FFT, and the information gained from the vibration signals can be used to predict catastrophic failures, to reduce forces outages, to maximize utilisation of available assets, to increase the life of the machinery, and to reduce maintenance costs related to health of machinery. The vibration measurements are taken periodically one time per month in general. Then, vibration signatures are monitored and compared previous measurements.

The vibration monitoring is based on principle that all systems produce vibration. When a machine is operating properly, vibration is small and constant; however, when faults develop and some of the dynamic processes in the machine change, the vibration spectrum is also changes. There are many studies on the vibration monitoring of the rotating machinery. Great amount of them concentrate on ball or cylindrical element bearing vibration monitoring.

However, under conditions of real environment there are many factors that affect the actual running state of the machinery. Thus, these factors must be taken into consideration. Studies related to real operating conditions of machineries were quite few. Gluzman monitored vibration of motor-generator system supported by ball and cylindrical roller bearings to predict impending bearing failures. He successfully identified impending failures of the bearing outer and inner races [1]. Al-Najjar observed many bearing vibration in paper mills for many years to predict remaining bearing life accurately. He also investigated effectiveness of vibration-based maintenance and proposed some findings [2].

Plants established to manufacture aerial or underground cables, telephone cables, bare conductors and fiber optic cables, steel rope manufacturing, pre-stressed steel ropes plants, etc. have similar wire drawing and stranding machines. All stranding machine includes a rotor loaded with bobbins (spools) loaded with drawn wires to strand required construction of conductor. Thus, unbalanced loads force machine bearings in all manufacturing time continuously. This type working conditions may reason failures of ball bearings early and unexpected accidents due to collapse of whole system. Some parts broken from the rotor body with high kinetic energy can destroy every thing by impacting.

### 2. Machinery park in wire processing plants

The first case study has been analysed in Plant A. Its machinery and processing lines can be separated into three groups. The first group is continuous casting line (CCL), which includes melting and holding furnaces, casting wheel and rolling machine to produce feedstock. Furnaces can be accepted as static machines except huge fan and its driver motor system. Casting wheel runs very low speeds but it is very sensitive to ball bearing faults. Milling machine is generally consists of 8-heads for EC grade aluminium but for production of 5xxx series alloy their construction is changed by increasing number of heads. The rolling head number may be 12 for aluminium alloys. Each head has a set of reduction gearbox and two set rolling mills with their ball bearings. The machine is very sensitive to bearing faults due to very heavy load occurred in rolling of continuous aluminium bar. If the CCL stops, all conductors manufacturing activity must be stopped gradually.

Second group machinery of the plant consists of various types drawing machines with single or double spoolers. These machines do not include big centrifugal forces due to very light mass of wires on rotating disc in the machine when processing of drawing. But centrifugal forces are very high when the spool takes up of the drawn wires. The small capstan mounted in the machine successively performs drawing process. They are turned under oil splash for making reduction of the wires with the help of the drawing die.
Third group is the most dangerous machines of a conductor manufacturing plant. These are stranding machines used for manufacturing of different type conductors. This division includes generally 7 wires tubular stranding, 12 bobbins tubular stranding, bow type 7 wires stranding, 54 wires (bobbin) rigid type stranding and 37 or 54 wires planetary type-stranding machines.

Generally, 7 bobbins tubular machines rotate with the speeds changing from 500 rpm to 1000 rpm. It depends on construction origin of the machine. European origin tubular stranding machines runs 1000 rpm but Far-East origin tubular stranding machines runs around 500 rpm. A typical property of them is rotation of the whole body on special composite rollers on condition that the shaft connected to back side of the tube is supported by a big ball bearing.

Bow types stranding machines can be considered as static type because only rotating part is bow and its mass is very low compared the machine body.

Rigid, tube and planetary types stranding machines are very critical in stranding of different type conductors because of loading in unbalance situations. A common rigid type-stranding machine consists of three or four blocks. These are blocks of 7, 12, 18 and 24 bobbins. But most of machines consist of 12, 18 and 24 bobbins cages.

In stranding of the conductor, rigid and planetary type machines are loaded with spools according to the wire numbers of layers of the conductor constructions. Thus, machine is forced to rotate with unbalanced loads due to loading of spools onto the rotor non-uniformly. Unavoidable unbalanced loading and also deflection of the body create extra dynamical forces on the ball bearings. Additionally, dynamical forces reason vibration of the main bearings of the rotor and its members. Consequently, welding points of the machine may cracks or some of the parts of the machine can failure before their designed nominal life. Spools or any other members may throw out from the machine due to increased vibration. A common rigid type machine 54 bobbins has included 54 bobbins (or spools). Each spool is generally 50 kg and it takes up approximately 100 kg aluminium wires and totally its weight is around 150 kg. The cage runs with speed up to 200 rpm. Planetary type machine has also similar properties.

To avoid risks of thrown out of the spools from the pintles of the cage, or similar accidents, which can reasons catastrophic failures, it is required to apply the best method for maintenance of the machines to perform production effectively and to keep active all safety conditions for workers and staff in whole working area.

The failures of stranding machines can be very critical because these lead to damage of machinery, production losses and personnel injury and death. So, the most important duty of the maintenance department is to prevent these failures before occurrence.

3. Maintenance organisations in production plants

There are many types maintenance techniques such as preventive maintenance, proactive maintenance, default type, discard type, offline–online type. Thus it is always a concern for the decision maker that which type of maintenance should be most appropriate or optimum. Decision makers, therefore, need to take into account the needs of their business, recommendations from the original equipment manufacturer, their own experience and that of other users of similar plant, and information on condition available from the plant offline or online. Condition monitoring using vibration analysis provides much of this assurance, and has developed such that access to online vibration data is available to experts who may be located remote from the plant. And the data, which is fed into the program, will suggest the right way to do the maintenance [3,4].

4. Necessity of PM and requirements in setting-up

Manufacturing companies have been practicing some form of preventive maintenance for years. Scheduled inspections and lube routes have, to some degree, reduced the possibility of catastrophic failure. Maintenance crews also may be replacing some machine components as part of a scheduled maintenance program. But now, vibration monitoring has allowed the industry to move beyond preventive maintenance and into a new generation of maintenance called “Predictive Maintenance” (PM).

The main focus of PM vibration instrumentation is to allow the user to confirm the condition of equipment and to accurately identify problem equipment before breakdown.

The benefits of avoiding catastrophic equipment failure in a manufacturing plant are obvious when considering that unexpected failure creates days or even weeks of costly downtime. Because of increasing competition in the manufacturing industry, the need for techniques to evaluate the health of equipment increases. An effective way of reducing the likelihood of catastrophic failure of equipment is through vibration analysis [5–7].

5. Implementation of PM to manufacturing plants

Each of the predictive techniques is highly specialized. Each has a group of systems vendors that promote their technique as the single solution to a plant’s predictive maintenance needs. The result of this specialization is that no attempt has been made by predictive maintenance systems vendors to combine all of the different techniques into a single, total-plant system. Therefore, each plant must decide which combination of techniques and systems is required to implement its predictive maintenance program. If a plant decides to use all of the available techniques, a total capital cost for instrumentation and
systems can easily exceed $150,000. In most cases, this fact alone would prohibit implementing a program; however, the true costs would be much higher. To implement a program that includes all of the predictive maintenance techniques would require extensive staffing, training and technical support. A minimum staff of at least five trained technicians and three highly trained engineers would be required to maintain this type of program. The annual cost for this operation would be extremely high. The actual labour and overhead rates of each plant, but the annual cost could exceed $500,000.

Because of high capital and operating cost, this type of program would have to save more than $1 million dollars each year to justify its costs. Even though this type of savings is possible in larger plants, most small to medium-sized plants cannot justify including all of the available techniques in their predictive maintenance programs. How do you decide which techniques will provide a cost-effective method of controlling the maintenance activities in your plant? The answer lies in determining the type of plant equipment that needs to be monitored. Plants with a large population of electrical equipment (e.g., motors, transformers, switch gear) should use thermographic or infrared scanning as their primary tool, whereas plants with a large population of mechanical machines and systems should rely on vibration techniques. In most cases, your plant will require a combination two or more techniques, but you may elect to establish one technique as an in-house tool and contract an outside source for periodic monitoring using the secondary techniques. This approach would provide the benefits that the secondary techniques provide without the additional costs. The optimums predictive maintenance program will, in most cases consist of a combination of several monitoring techniques. Because most plants have large population of mechanical systems, vibration techniques will be the primary method required to implement a total-plant program [8–10].

6. Dynamics of rotating machines

To indicate the requirement of regular measurement of ball bearing condition in manufacturing plants, which have rotating machines run under unbalanced or balanced loads, two case studies have been analysed. These two cases represent most of the plants in industry. Similar machines are also used in tyre steel wire plants, steel rope plants, pre-stressed steel wire plants, telephone cable plants, conductor manufacturing plant and other wire products manufacturer’s plants, etc. Wire processing plant is chosen because machines used in wire industry are a lot of different types small and big rotating machines. Rotating machines, which are rigid type, planetary type tubular type and bow type, are used for stranding of conductors in different constructions. So, machines and their rotors are constructed according to size of spools loaded with wires, number of the wires required by wire-stranding construction of the specifications and number of the wires available on the layers of the conductor or steel ropes.

The main characteristic of the rotating machine that is well known from dynamics is rotating around fixed axis with uniformly distributed loads. If this condition is not realised under working condition, some dynamical loads on ball bearings occur. These forces reason failures of the ball bearing in any unexpected time and reasons accidents.

Consider a rotor of total weight "W" supported horizontally on two bearings a distance "l" apart as shown in Fig. 1. The "z"-axis is taken as the fixed axis of rotation and the "x, y" axes are attached to the rotating body. During the rotation there will be dynamic reactions at the support of the rotor.

We shall determine these dynamic reactions "X₁, Y₁, X₂, Y₂" in the rotating "x, y, z" system and it is to be understood that, if the total bearing reactions at any instant are required, the dynamic reactions, located in correct direction at that instant, must be added to the static reactions caused by the weight of the rotor. The equations of motion of the mass center give us directly:

\[ \sum F_x = m\ddot{x} \]
\[ X_1 + X_2 = -m\dot{x} \omega^2 - m\dot{y}\dot{\omega} \]
\[ \sum F_y = m\ddot{y} \]
\[ Y_1 + Y_2 = m\dot{x}\dot{\omega} - m\dot{y}\omega^2 \]

Fig. 1. Dynamics of rotating machine.
The moment of the momentum equations gives

\[-Y_2l = I_{xz} \omega^2 - I_{xy} \omega\]

\[X_2l = -I_{xy} \omega^2 - I_{xz} \omega\]  \hspace{1cm} (5)

(6)

Knowing \(m, \omega, \dot{\omega}, x_c, y_c, I_{xz}\) and \(I_{xy}\), we can find the four unknown dynamic reaction components from these four equations.

If the product of inertia are zero, and if the center of mass lies on the axis of rotation so that "\(x_c = y_c = 0\)" then it will be seen that there are no dynamic reactions. The rotating body is then said to be dynamically balanced. If the center of the mass lies on the axis of the rotation so that the system is statically balanced, there is no gravity torque for any position of the body, but there may steel be some dynamic unbalance because of the presence of product of inertia terms. Since for static balance the mass center has zero acceleration:

\[X_1 = -X_2\]

\[Y_1 = -Y_2\]  \hspace{1cm} (7)

(8)

The dynamic reactions hence exert a couple on the rotor.

It is thus seen that static balancing of a rotor is not in general sufficient to remove the dynamic reactions, since a rotating dynamic may steel be present. Complete dynamic balance is achieved by adding to the system two balance weight, so located that the dynamic reactions set up by the balance weights are equal and opposite to the dynamic reactions resulting from the original unbalanced rotor. This is equivalent to making the products of inertia of the rotating system zero, by addition of the extra balancing weight [11].

Finally, stranding machines with big and small rotors used in wire product industry have rotors different than air compressors and gas turbines. Rotors in turbo-machines are not liable to dynamic forces under normal conditions. Because their rotors are balanced dynamically in construction stage. But rotors of stranding machines are loaded with spools with weight of 150–300 kg according to conductor constructions and material properties. Thus, bearing of the rotors of the stranding machines in wire industry are exposed to very high dynamics loads, so condition of the ball bearing should be regularly controlled.

In all wire processing plants there are various kind rotating machines such as rigid, tubular and planetary stranding machines and their running principles are different but rotor dynamics under balanced or unbalanced loads similar each other and the theory explained above is valid all of them [11].

7. Loading of the spools to the stranding machines according to conductor constructions

Stranding machines are considered as a perfect example in explaining of the ball bearing forcing due to unbalanced loading and a source of possible accidents due to running mistakes of the workers when loading and unloading of them. Because, these type machines are 45–60 m length and their rigid and planetary types consist of three or four rotating bodies. On the other hand, compressor and gas turbine rotors bodies are kept in the cover as constructed and any changed in their balances, it is possible that machine is collapsed due to deflection of the rotor under unbalanced load because there is very limited clearance between rotor and case of the body. But, stranding machine are different these types constructions. There is not high sensitivity to the unbalanced loading as seen in the rotors of turbo-machines.

Reasons of the catastrophic failures depend on several factors in the manufacturing industry. From the experiences, most of them are due to wrong running of the machine than instruction manual, insufficient maintenance and operator mistakes, which is due to over encourage and taking very dangerous operative risks.

In the cable industry, except stranding machines, most of machinery can be considered as statically working. However, it should be never forgotten that predictive maintenance is not valid only dangerous rotating machines but also statically working production machines.

The standing machines consist of rigid type, planetary type, tubular type and bow type. Bow type machines run silently and the rotating part is only very light bow, which is used as stranding of the wires Al and Cu. Thus centrifugal forces in any dangerous condition, which is locking of the ball bearing of the cradle, are very low when compared to that of the tubular, rigid and planetary type machines.

Vibration phenomenon occurred in the stranding machines is due to unbalanced loads as explained before. This is unavoidable situation for the persons who are interested in the production activities. These unavoidable loading situations create unbalanced loading in the ball bearing of the cage and reason vibration on the whole rotating system. Unbalanced loading is an essential reason in decreasing of the nominal life of the ball bearings.

Doubtless, in designing stage of the machine unexpected forces are considered by applying safety factors to strength conditions of the cage members. However, the strength of the materials working under cycling loading depends on time. Loading plan of some aluminium conductors in respect to construction properties has been given in Fig. 2, which shows balanced and unavoidable unbalanced loading to stranding machine.

8. Case study-1 from Plant A: catastrophic failure of 7 bobbins tubular stranding machine

Tubular stranding machine consists of main drive electric motor, tube, tube carrier rollers, spool cradles, gearbox, capstan and take-up. The stranding tube has a main bearing at the back side of the machine and whole body is supported by rollers. If
the surface of the rollers has any roughness it will reason immediately high level of noise and vibrations at the main bearings, tube covers and stranding tube with high amplitudes. However, the most sensitive part is the bearings of the cradle, which is connected to the tube by the circular plates welded inside circumferentially. In 1 + 6 type tubular stranding machine, there are 6 cradle and 12 ball bearings for supporting it to the tube.

The stranding machines have got very sensitive insurance mechanism to prevent probable accidents in manufacturing operations. However, one of them threw out spool pintled in the second cradle. When the machine was running to manufacture 7 wires AAC conductor, right ball bearing of second cradle locked suddenly and the machine was collapsed. When it

Fig. 2. Loading plan of the stranding machine according to construction of the conductors indicated in the left column. Unsymmetrical loading of the machine reasons extra loads on the ball bearings.
had occurred the machine was running 1000 rpm. Thus all kinetic energy of the machine was transferred to the pintles. The second cradle with locked ball bearing has been presented with spool in Fig. 3.

This unit is guarded by the emergency stop circuit, which is activated by changing of the mercury level in the small tube. The closed tube with mercury connected by electrical-circuit is mounted in the pintle mechanism.

If the position of the cradle loaded with spool is chanced higher than set angle anyway from the horizontal neutral position such as increasing friction due to completion of the nominal life of the ball bearings of the cradle, insufficient lubrication

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**Fig. 3.** View of the cradle of the tubular stranding machine and location of the spool. On the right side, disc springs actuated by air pressure has been shown clearly.
of the cradle bearings, the safety organ will be triggered by changing the position of the mercury in the tube and closed the electrical-circuit to give an input to main driving motor to emergency stop.

This is very sensitive mechanism of these machines and works perfectly. In our case, the machine stopped in a few seconds but the energy on the machine is very high.

Cradle and its auxiliary equipment is the main source of all dramatic accidents because the spools are not fixed to its place rigidly. These are general properties of the cable stranding machines.

The type of the stranding machine, which is liable to catastrophic failure in Plant A is given as follows:

Type: 1 + 6/tubular stranding machine;

The machine has been running perfectly with the maximum speed at 1000 rpm and efficiency and product quality satisfies all specification requirements.

When the bearings of the cradle had locked, gained kinetic energy of the machine turning in 1000 rpm transferred suddenly to the spool of the cradle. The locked cradle with spool starts to rotate together but it is impossible because the speed of the machine is very high. Moreover, tubular machine is not constructed as rigid type machines. Kinetic energy of the spool transmitted by the rotating body owing to suddenly locking of the bearing is around $E_K = \frac{1}{2}mV^2$ or $E_K = \frac{1}{2}mxr^2$. Finally, excessive kinetic energy forces the discs springs of the pintles and beat of their reaction forces. Thus, pintles are opened and the spool, which has 150 kg weight, throws outs from the machine by making projectile motion.

The pintles are actuated with 6 bar air pressure (see Fig. 3). When the air is filled into the piston of the pintle, the piston applies tensile force and the disc springs are bent and the pintles are opened for loading of the spool. When the air pressure is disconnected, the pintles are automatically closed due to the forces exerted by disc springs. If anyway this closing force of the pintles is overcome, the pintles are opened and spool will be free.

The sudden released energy of the machine due to locking of the cradle's ball bearing overcame pintle's closing force and centrifugal force reasoned to thrown out the spool from the machine. The spool impacted to the tube and created serious bending on it.

View of the spool after thrown out from the machine has been shown in Fig. 4. Bending of the tube due to impacting of the spool thrown out from the machine has been indicated in Fig. 5. The cradle's locked ball bearing due to insufficient lubrication is shown also after dismantling for analysis the reason of the accident in Fig. 6.

Perhaps the bearings make several announcements for weeks to production operators, engineers, and maintenance engineers and maintenance service men by changing vibration signature characteristics. But the factory has not got the predictive maintenance culture, thus vibratory announce made by machine is not heard by responsible persons between the noisy environment due to running of them together. As a conclusion the catastrophic failure occurred and by chance it results in no serious injury and no death.

However, these type failures can be easily detected before taking place of the accident with the help of vibration analysers.

![Image](image_url)
In the presented first case, repairing of the production machine has been completed in 2 month. This machine can manufacture both 7 wires AAC and ACSR types aerial bare conductors. Monthly production quantity can be assumed as the combination of 50% AAC and 50% ACSR conductors. So, total loss of the company can be calculated from Table 1 as minimum 402.000 $. This value does not contain also some of the shares of fixed cost of the plant.

![Image](image1)

**Fig. 5.** Bending of the rotating-tube due to impact of the spool thrown out from the cradle and view of the location of the dismantled ball bearing after accident.

![Image](image2)

**Fig. 6.** View of the locked ball bearing dismantled from the failed cradle, SKF 6011-2RS.

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### Table 1
Total loss of net production profit and labour in the plant due to absent of predictive maintenance techniques.

<table>
<thead>
<tr>
<th>Aerial conductor products</th>
<th>Monthly conductor production (ton/month)</th>
<th>Sales prices LME:AL-2800$/ton</th>
<th>Net profit $/ton from expected sales</th>
<th>Labour Loss</th>
<th>Net Production and Labour Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAC</td>
<td>180 ton/month</td>
<td>3500$/ton</td>
<td>Total sales = 630.000$/month</td>
<td>Three shift working 3000$/month</td>
<td>Repairing time = 2 month 2 × (3000 + 126,000) = 258,000$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Profit.%20 630.000 × 0.20 = 126,000$/month</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACSR</td>
<td>450 ton/month</td>
<td>3000$/ton</td>
<td>Total sales = 1350.000$</td>
<td>Three shift working 3000$/month</td>
<td>Repairing time = 2 month 2 × (3000 + 270,000) = 546,000$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Profit.%20 1350 × 0.20 = 270,000$/month</td>
<td></td>
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</tbody>
</table>
9. Failure detection with vibration analysis: case study-2 from Plant B

As mentioned before two case studies have been analysed by collecting data from real working conditions not from the laboratory environment. Because, one of the aims of the case analyses is to show clearly the potential risks at ferrous and non-ferrous wire processing plants and also another factories with similar machinery parking. Second aim is to show the most powerful method used in elimination of those risks coming from rotating machines. These risks threat not only the machines but also workers and others persons as potential killer or source of heavy injures.

Thus, in the second case the health of an electrical motor working as main driver unit of the rubber processing machine in Plant B has been considered. In the data analysis CSI-Model 2110 Machinery Analyser has been used in data collecting. Then, data acquisition system Master Trend software has been loaded and its reports were followed. The evaluation program Master Trend has functionality about the subjects; machine database, route definition, auto problem report, expert analysis, diagnostic tools and management report. Data collected from the production machines have been evaluated as follows with the help of the vibration spectrums [12,13]. The power of the vibration analysis to detect bearing failures before occurrence has been summarised with Figs. 7a, 7b, 8a and 8b.

A typical waveform a fault on the outer race is a damped transient vibration signal, having non-varying peaks of initial amplitude, which takes place at the outer race defect frequency. This is simply because the defect on the stationery outer race will always be subjected to same amount of load and the peaks of the initial amplitudes of impacts are always at the same level.

Fig. 7a indicates trend view of the electric motor of the machine with data collected from the June/01/2001 to the April/19/2006. The measurements related to vibration signature of the electrical motor were recorded in vertical direction. Increasing stages of the failure of the ball bearings is shown in the graph easily day by day. From the trend view, the operation day to change them with new ones is April/19/2006. Fig. 7b shows velocity versus frequency of the vibration of the ball bearing taken on April/20/2006 after completion the changing of them with new ones.

![Fig. 7a. Trend view of the motor bearings of the plastic extruder working in Plant B.](image)

![Fig. 7b. View of the velocity versus frequency of the ball bearing.](image)
Fig. 8a. Trend view of the electrical motor started from June/01/2001 and continued up to April/19/2006. These data were collected from the measurements in the axial direction of the electrical motor.

Fig. 8b. Measurement of the motor bearing of the extruder on the horizontal axis and drawing of data velocity versus frequency after changing of the ball bearings.

Fig. 8a is the trend view of the electrical motor started from June/01/2001 and continued up to April/19/2006. These data were collected from the measurements in the axial direction of the electrical motor. Fig. 8b shows frequency versus velocity of the bearings. View of the dismantled ball bearing SKF 6311-2RS from the electrical motor with defect on the outer ring has been shown in Fig. 9. Typical surface profile of defect-free condition of an outer ring of a ball bearing has been presented in

Fig. 9. View of the ball bearing dismantled from the shaft of electrical motor with defects on outer race, SKF 6311-2RS.
Fig. 10a. Typical surface profile of point defect condition of the outer ring of a ball bearing has been presented in Fig. 10b [14].

Fig. 10a. Surface profile of defect-free condition of outer ring of ball bearing.

Fig. 10b. Surface profile of point defect condition of outer ring of ball bearing.

Fig. 11. View of rigid type conductor stranding machine from back side with the blocks 7 + 12 + 18 + 24 bobbins, respectively. Total length of the rotor of the stranding machine is around 60–80 m and height is around 2–3 m.
10. Conclusion

Maintenance concepts of the two companies in management of manufacturing process have been analysed by considering machine and production safety. Results have been determined as below:

(a) The machines used in conductor and similar wire product processing plants such as steel rope, pre-stressed steel rope, tyre steel wires, telephone cable, etc. are forced dynamically by unbalanced loadings due to construction requirements of the wires (see Fig. 2). A typical rigid type wire-stranding machine for manufacturing of conductor or steel rope has been shown in Fig. 11. These machines, which can be considered as constructed several rotors with the weight of the spools changing related to processing time, have potential for catastrophically failures owing to locking of the ball bearings under insufficient maintenance service conditions. Thus, safety situations of workers, machines and products depend on the maintenance level applied in the plant. Supports constructed by ball bearings as a most critical part of rotating machines must be observed regularly by persons of production and maintenance departments to detect the abnormalities with the machines. In prevention of the accident analysed here, vibration signature of the machines should be checked up according to a software program regularly. Data collected from the machines must be evaluated systematically by that program and by experienced persons to find out failures before occurrence as indicated in the analysis of case study-2 from Plant B.

(b) It has been shown that predictive maintenance eliminates two main problems in the industry simultaneously. Using PM technique, conditions of the machines are observed regularly. However, this is not a unique problem of the manufacturing companies. Companies are also responsible from the safety working conditions of all workers and staffs in the plant. Perhaps the most important problem in the manufacturing areas is the guarding of the workers from the threats, which are created by rotating big masses with high centrifugal forces. If vibration signatures of rotating machines show smoothness, the failure potential of the machine will be in minimum level. Thus, when the rotating stranding machines run without vibration, men–machine and production will be in safety. Because in the running stage of the machines, some of the workers are available between of them for maintenance or production aims. Thus it must be learnt from the case that predictive maintenance PM is not only a technique that is used to detect failure conditions of the manufacturing machines but it also guards the workers and staffs from the potential hazards in the manufacturing areas.

(c) It is obvious that organisation of the predictive maintenance must result in increase of the number of the staff and fixed cost of the company. In addition to them, initial investment cost for implementation of the PM to the company is also high. These cause some disadvantages in getting permission from the top management for the technical staff that requires adopting this technique into company. However, maintenance and production departments know very well the power of the PM in management of the manufacturing process. So, they can tell them clearly the importance of the regular controlling of the machine conditions to save the money and ways in getting rid of possible risks summarised in the article.

References