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Increasing Profitability Supported by Innovative Methods and Designing Monitoring Software in Condition-Based Maintenance: A Case Study

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***Abstract*—**In the present article, a new method has been developed to enhance the application of equipment monitoring, which in turn results in improving condition-based maintenance economic impact in an automobile parts manufacturing factory. This study also describes how an effective software with a simple database can be utilized to achieve cost-effective improvements in maintenance performance. The most important results of this project are indicated here:

1. 63% reduction in direct and indirect maintenance costs.
2. Creating a proper database to analyse failures.
3. Creating a method to control system performance and develop it to similar systems.
4. Designing a software to analyse database and consequently create technical knowledge to face unusual condition of the system.

Moreover, the results of this study have shown that the concept and philosophy of maintenance has not been understood in most Iranian industries. Thus, more investment is strongly required to improve maintenance conditions.

***Keywords*—**Condition-based maintenance, Economic savings, Iran industries, Machine life prediction software.

I. Introduction

MACHINES are born dead and the life has been simulated for them through maintenance systems. Actually, all managers of simple or mechanized manufacturing processes are always concerned about infrastructures exposed to erosion or destruction.

High-speed technological innovation and also use of just in time (JIT) philosophy and lean and agile manufacturing have made production process vulnerable to breakdowns [15], [19], [34].

Therefore, maintenance system as the knowledge of maintaining, effective stability and activities monitoring, has been considered in administrative activities with live and current nature. In other words, the machines are designed to achieve a certain goal and the lifeless structures need a live flow of effective and coordinated activities to act more efficiently in their determined life time of working. Generally, the machines are born dead and they would need reviver activities to be stable; so that they are able to delay or sometimes stop the countdown in their working life time. Due to efficient stability in machineries and equipment performance, various systems have emerged and formed over time and they have been applied based on objectives, situations, type of investment and climate expectations.

The most common maintenance strategies are failure-based maintenance, preventive maintenance, condition-based maintenance, reliability centered maintenance and total productive maintenance. Research into these strategies has been conducted by [12], [22], [23], [24], [27], [35] among others.

When reviewing the history of the introduced policies, it can be stated that condition monitoring is the most successful policy in the advanced and organized maintenance process. CBM is a predictive strategy that acquires data from various ways of machinery and indicates the equipment condition [20]. An ideal condition monitoring system receives data and uses techniques and technology for simulating the operational status and finally, it will predict time and type of real breakdown [33].

Several authors have proposed the various CBM policies and optimization methods, see for example [5], [16], [17], [18], [30], [31], [32], [35], [36], [37] among others.

Of course, the condition is not always based on predetermined issues and a new approach is required to find appropriate and efficient strategies in controlling machines, before we lose such useful agents. This point of view has been studied and analysed in the present research work.

The high precision of assessing machine condition and the followed decisions depend on proper technical performance of monitoring system, according to [1], [3]. Higher precision of machine condition assessment can improve availability and business effectiveness, predict stoppages and reduce costs [9], [14].

In this study, we have tried to design an appropriate method of maintenance based on available facilities and CBM technique. This method is based on receiving information from the machines performance and then transmitting them as analysable data form; a simple and effective software has been

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designed to analyse data. Through this software, responsible personnel are able to plan for checking and possible repairs at the time out of production before the facilities would cause the line production stop and impose high costs.

It should be mentioned that machinery and equipment analysis in advance of applying common methods of maintenance will provide an opportunity to use engineering knowledge to control unusual conditions. This will allow us to design maintenance process based on equipment condition and avoid losing money caused by incompatibility operations with the equipment. So that the personnel involved in the process would be able to take wise actions to reduce the costs without considering probable complexities in maintenance process, and receive obvious and tangible results with not so complicated equipment.

Referred to the given issues above, following points are the most important goals in performing the project:

1. minimizing uncontrollable common costs, including unplanned stoppages, rework and wastages caused by unusual condition of machines and losing raw materials and energy;
2. Identifying failures and their causes in early stages of occurrence;
3. Ordering spare parts as required and consequently reduce the costs of capital dormancy;
4. Providing clear perception about maintenance concept and its economic effects among Iranian industries;
5. Designing a software to receive, process and analyse information, and determine the approximate life time of machine and also provide predetermined strategies for special conditions which are applicable to a wide range of equipment;
6. Reducing human error and prevent the re-occurrence, so that all personnel, including maintenance unit and other parts, would be able to decide with the lowest error and control machine condition.

II. Maintenance in Iran Industries

When the failure occurs, inefficient maintenance is the first cause coming to mind, but when there is no failure, it can be difficult to prove that this has been due to efficient maintenance as found by [1], [6], [35].

The role of maintenance in companies' profitability and productivity has been proven; see e.g. [1]-[5], [8], [10], [13], [22], [25], [26], [28]. Nevertheless, its role is not well understood in Iran industries and failure-based maintenance policy is still being applied as the most common strategy in Iran.

In fact, one of the main reasons to reject the position of the maintenance is lack of tangible economic effects of the process on the organization. Some of the maintenance costs like labor force, spare parts, training and etc. are easy to identify and calculate. Therefore, the organizations try to reduce these costs, but indirect maintenance costs such as maintenance impacts on product quality and loss of market shares are difficult to calculate. Therefore, these impacts are ignored in considering the position of maintenance. (For more information about direct and indirect maintenance costs refer to [5]).

The implementation of the proper maintenance can help to reduce maintenance costs, improve reliability and prevent the occurrence of system failures. (See among others [12], [21], [27], [34], [35], [38]).

The increasing investment in maintenance is considered as a very important factor to achieve competitive advantages. In spite of the increasing awareness of maintenance and its economic impact on company profitability, maintenance is still regarded as a cost centre. This could be due to the difficultly of calculating maintenance costs [8], [11]. This point of view, which considers the maintenance as a cost centre, has been also operated in Iran. The issue would become completely clear after reviewing Iran industries and considering the maintenance position in view of industrialists.

In the first step, we designed questionnaires to achieve accurate statistics of maintenance position in Iran industries. (The given ideas in article of [7] were applied to design this questionnaire). Designed questionnaires contained 15 questions. The questions covered all aspects of maintenance system; also, respondents selected their answers among standard responses in order to prevent respondents' interpretation of the questions. According to the obtained statistics from The Statistical Centre of Iran, the total number of industrial workshops with at least 10 personnel was 26128, due to the high number of these workshops, access to all of them was not possible, for they were widespread throughout the country and also it would prolong census process. Therefore, we decided to run this empirical study within companies that had at least 100 personnel. 3822 companies met the criteria. Questionnaires were designed and distributed among 3822 companies via email or fax. Only 143 responses were received. Following results were obtained in terms of maintenance policies used in Iran industries through analysing the answers:

73%FBM (Failure-based maintenance), 21%PM (Preventive maintenance), 5%CBM (Condition-based maintenance), 0.3% RCM (Reliability-centred maintenance) and 0.7% others.

The main results of this study show that the role of maintenance is not properly recognized in Iran industries. (This is similar to a result published by a previous study, see [7]) And also based on the answers to the questionnaires, unawareness on the various strategies applied in maintenance process and lack of sufficient training on these strategies could be considered as the most important reasons for the question 'why FBM policy has been applied as the most common strategy in Iran'.

III. Case study

AR Machine Company is an automobile parts (steel wheels) manufacturer with an annual production capacity of 1,000,000 parts. It has been equipped with the production line of electrodiposition painting and higher capacity of domestic production line. Therefore, 500,000 square meters of vacuum capacity has been allocated annually by the company to paint parts which were produced by other manufacturers of automobile parts as per to the programs of the company's business plan. Although the maintenance policy in this company was preventive maintenance, process performance has changed to failure-based maintenance, due to lack of performing determined prevention program, absence of appropriate information and disorder in administrative programs. Thus, the absence of capability in controlling defined and systematic operation, without reasonable and reliable data, has caused maintenance system to lose its effectiveness in the sets which are under its supervision.

A. Reviewing Problems and Downtime Records

As the first step of operating project, we proceeded to consider organization problems to find the most critical machines among 47 machines. Painting line was identified as the most critical unit through the review of the failure records and repair, maintenance costs and the effect of breakdowns on customers in 2009.

The painting line of this collection has been equipped with electrodiposition system. And it has been able to paint steel wheels, body and safety parts of an automobile with 600 m2/hour capacity. As stated earlier in this article, this unit has higher capacity of domestic production line and therefore, 500,000 square meters of vacuum capacity has been allocated to other manufacturers.

Thus, stability of production systems in this unit will guarantee the continuance of contracts to perform services out of organization. Time limit in maintenance operation and full time function of the machines are important points in stability of the unit.

B. Identification of Critical Station

Therefore, we started our study on the painting line. But as shown in Fig. 1, the painting line consists of 11 work stations and each of them has a different influence on the performance of the painting unit. Therefore, in the next step, we studied all 11 stations and the phosphating station at pre-treatment line of painting unit was identified as the most critical station through cost factors and stoppages duration, as illustrated in Fig. 2.

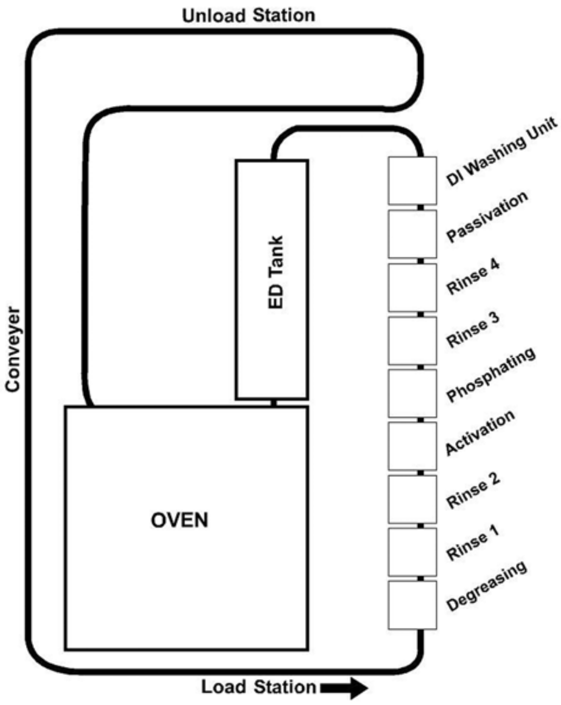

Fig. 1 A schematic of the painting line stations

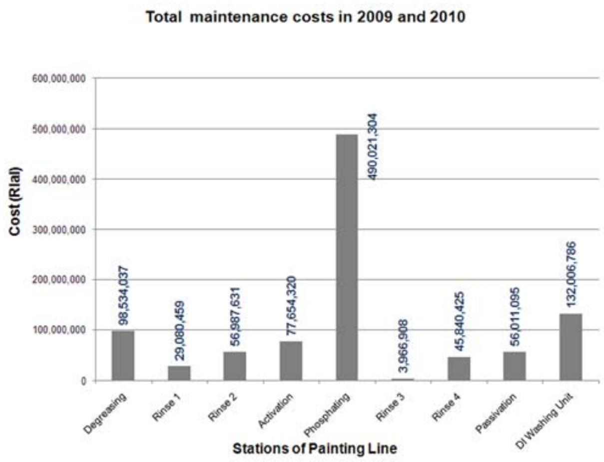

Fig. 2 Comparing painting line stations to identify the most critical station in terms of cost

Phosphating station at pre-treatment line of painting unit is responsible for forming a phosphate layer on the parts. In this unit, phosphatation has been accomplished through direct spray of the solution at 450c. The solution is sprayed by nozzles and while the conveyor moves in tunnel of pre-treatment line.

Eight nozzles spray the materials from all directions on the parts in a path of 6m length. The most important factor for performing the process properly is to spray simultaneously by 8 nozzles and set the appropriate temperature in order to place on the part which requires filtration unit to act properly and efficiently.

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Phosphate materials, remained from the spray and placed on the parts will return to the main tank. When the operation is done, some sludge will be added to the solution which must be separated by the filtration unit. The amount of produced sludge through the operation should be controlled and it should not exceed 100 parts per million (ppm), so, operation of sludge removing is so important. Increasing the sludge value in solution would create sediment in heat exchangers, nozzles, pumps and then they will be blocked. The high rate of sludge in the solution will result in its inappropriate level in the paint and phosphating process and it can also block the nozzles and interfere in the spray process. Thus, interference in filtration unit shall make the phosphating operation stop and create qualitative problems. As per to these circumstances, the painted parts would not be so resistant against corrosion. A schematic of this station can be seen in Fig. 3.

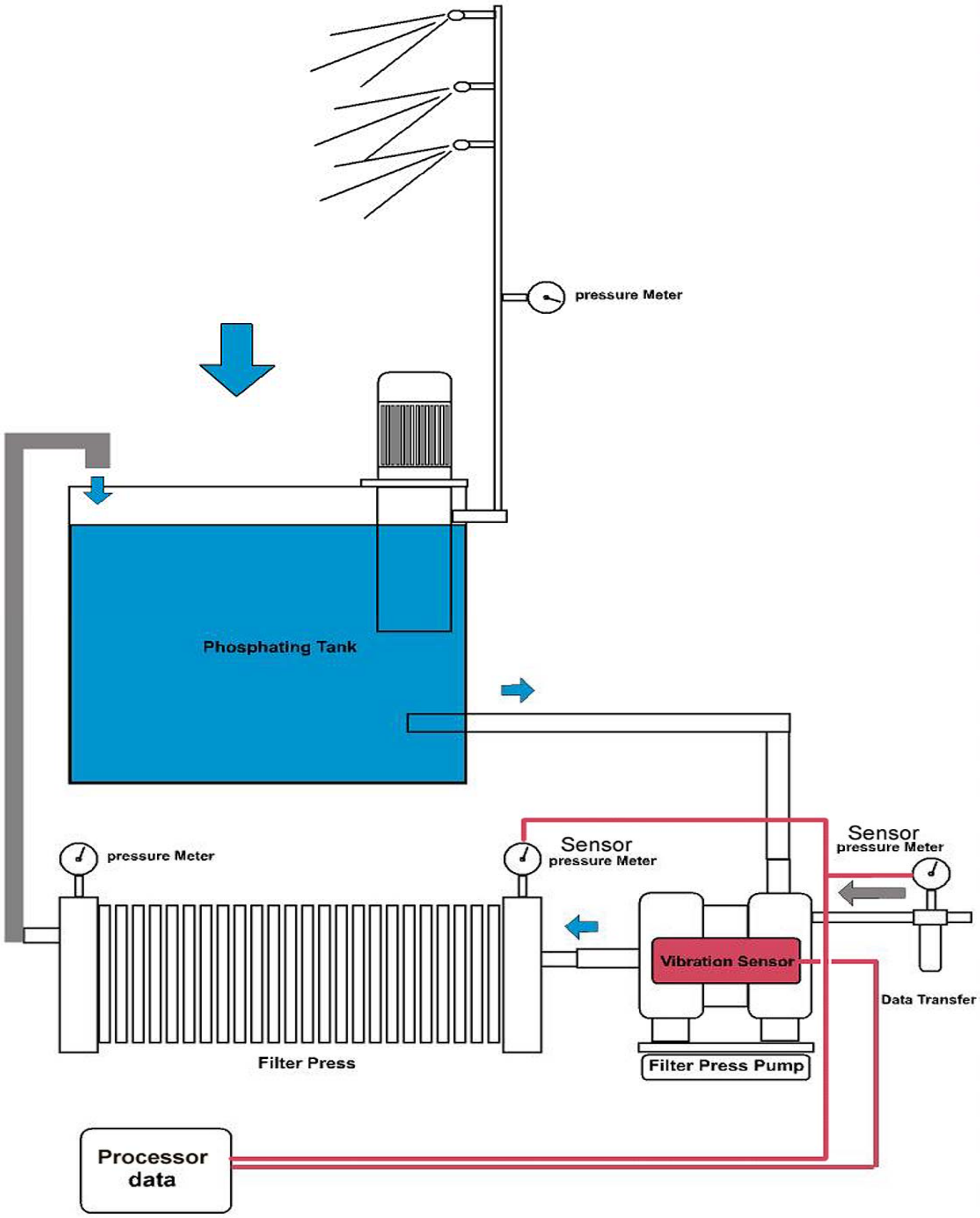

Fig. 3 A schematic of phosphating unit and location of the sensors installation

C. Reviewing Work Process of Maintenance Unit in order to Identify and Problem Solving

Data collection is one of the most difficult jobs, in the development stage of a maintenance plan [35]. In this study, one of the problems was lack of information on the machine records under study. So, we began to study the unit in terms of available records from the second half of 2009 in order to reduce stoppages and cost effects.

Following example indicates one of the occurred failures and the maintenance performance about that failure and also imposed costs on the factory:

In the second half of 2009, a failure has been observed in pump system at filter press which belongs to the equipment of phosphating tunnel in pre-treatment unit. A repair and replacement operation has been considered; however, due to lack of records for qualitative problems and rareness of some spare parts, the defected system was repaired incompletely by applying a set of new spare parts, half of them were renovated old parts. Consequently, after commissioning, the system faced the problem for the second time, because of high work pressure and inadequacy of the parts, therefore, it stopped one week after repair operation. The lifecycle of new parts was so short due to using old parts in the set, and therefore, disturbances in the machine performance had occurred. Buying process of foreign spare parts was estimated to last more than one month. In regard to line stoppage, customer pressure for in-time delivery and lack of prediction about the appropriate strategy, the maintenance unit decided to apply the same equipment in commissioning system. Similar equipment was bought and installed, but the system stopped after 19 days because the equipment was inefficient and incongruent with machine condition. During long stoppages, the maintenance unit used an assisting protocol in order to commissioning and stability the line. Applying the given method resulted in losing considerable phosphate materials and also some disturbances in qualitative produced parts. For example, the amount of increasing consuming materials and their costs in 2009 and 2010 has been shown in Figs. 4 and 5 respectively.

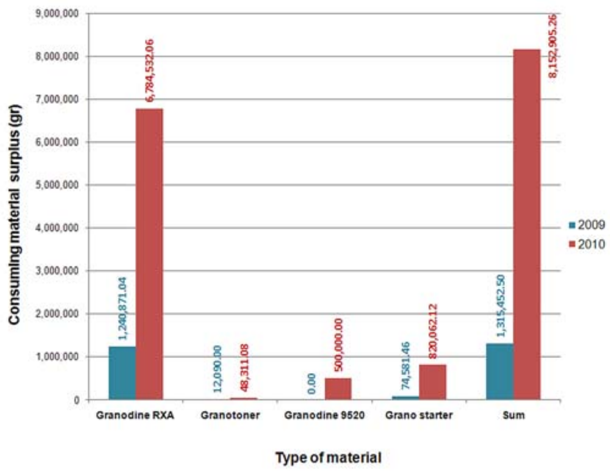

Fig. 4 Consuming materials surplus in 2009 and 2010

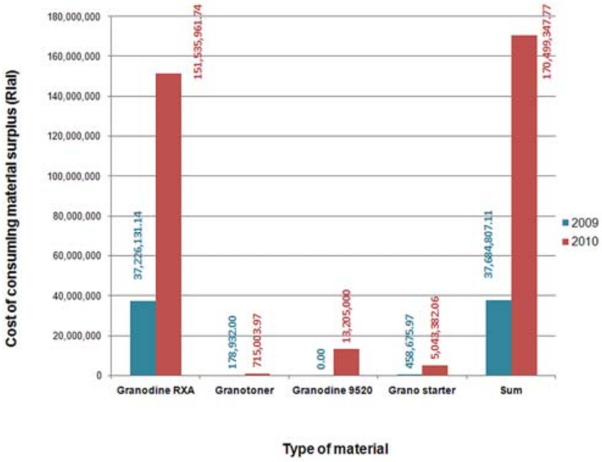

Fig. 5 Cost of consuming materials surplus in 2009 and 2010

D. Design and Layout of Hardware of the Received Data

The result of investigation indicated that the best solution is the idea of monitoring the equipment for online control of the line. And then, analysis of equipment performance by measurable control parameters to diagnose the life time of system was placed as priority. Thus, there began a process of considering strategies to receive data from online condition of the equipment. With regard to analysis of the presented plans, the most reliable way is based on applying sensors of transferring information through available facilities and reliable parameters. In this step, it should be determined that which type of information is to be transferred. Since the pumps transferring the fluids were pneumatic and stroking, frequency and pressure were recognized as the most effective factors to receive the information.

Sensors were selected and installed at the most effective locations for the given parameters. These sensors were responsible measuring generated pressure at suction and discharge of the pump and also the pump stroke. Once the diaphragm opens and closes, the value of fluid pressure at discharge is sent and recorded. In this way, the interval between two strokes created by each suction and propulsion of the pump is recorded using sensors sensitive to vibration and the time of each suction and propulsion is calculated. Thus, the combination of these data including the interval between two storks and maximum generated pressure will be the base of evaluating the machine performance.

The sensors consist of one sensor to measure the vibration and two for the pressure which have been demonstrated in Fig. 3. Here, a simple processor is required to analyse the recorded data.

E. Description of Equipment Operation

A pneumatic pump with a suction pressure of 7bar is working at its maximum flow rate with standard liquid density. A sensor receives and sends the pressure of compressed air at the suction in certain time intervals. Fluid is transferred through the pump with defined pressure into the filter press. Discharge pressure of the fluid is received by the second sensor simultaneously with the process of receiving information in vibration sensor; then this data is transferred and recorded them into the data logger. Later, the data will be processed and analysed by the software which is specially designed for this analysis.

F. Software Description

The software is designed to process the received information and adjust them with the criterion of performance measurement.

i. Input page

As it can be seen in Figs. 6 and 7, initial settings related to the received information from sensors have been placed at this page. At this step, time schedule for receiving information is defined by the sensors and they will be coordinated depending on the requirements of analytic operation. This section has been designed generally and it can receive any information with defined conditions; and then record this classified information as predicting database.

The data is received by the system's processor in accordance with the defined trend and then it is converted to comprehensible output data in both visual and textual forms after being analysed, compared and replicated. In the visual part, the operator can observe the machine condition on a diagram. The diagram will give the operator an opportunity to monitor the system online. At this part, any unusual condition would be reported as alarming sign and while the operator sees the unusual condition s/he could enter the decision making section and observe administrative strategies in terms of generated conditions.

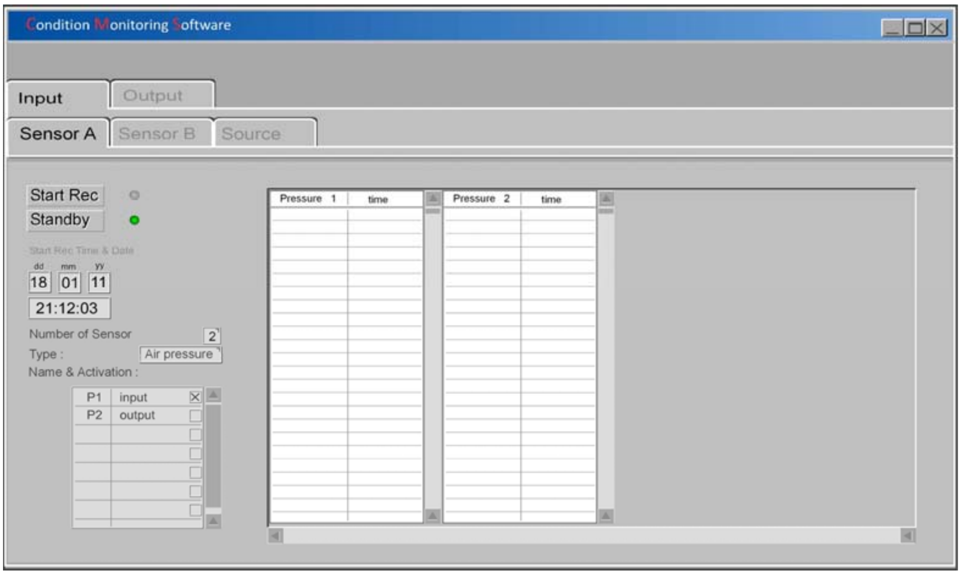

Fig. 6 Scheduling setting page of sensors receiving information

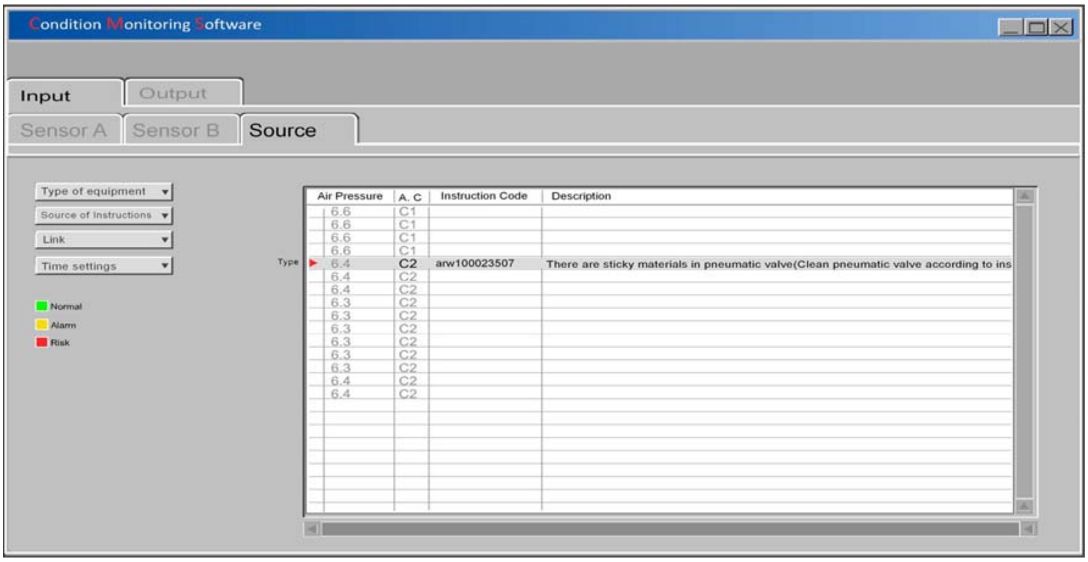

Fig. 7 The page for entering database failure and creating links with alarm type of the machine

ii. Output Page

This page contains all the settings in connection with system output, which can be expressed as diagram or data. In this part, scheduling information in database has been sent to processor section through adjustable methods. The analysis could be seen at the second part of this page which can be regulated. Also, the goal and area of the acceptance information are determined here and the relevant data can be drawn out from the data recording section. So, the recorded information in a specified period has been studied for the first time and there begins a standardization of failure behavior of the machine. For example, initial basis for determining the lifetime of the system will be the association between the stopping time of working and the recorded information at that time. Receiving and processing this information for the second time or even more would be more accurate and more reliable.

The system has analysed the received information using multistage analysing in contrast to previous recorded data and then it has corrected and updated the accuracy of outputs. For example, after a five-step failure, correctness of the data in regard to the equipment's lifetime is far higher than the first event of breakdown.

G.Life Reduction Diagram

The diagram consists of two short-term and long-term plans that will be displayed simultaneously. Short-term table shows the operation flow within the last hour and the long-term table presents the monthly operation. The pressure is shown versus the time of each frequency; so that the processor can draw the diagram by combining the data simultaneously, as illustrated in Fig. 8.

The horizontal red line determines the breakdown area and the yellow line represents that the operation is lower than normal condition. The situation created and the diagram depicted in relation to these two lines denotes some kind of probable condition in system which is linked to the actions related to the process. All defined actions of preventive maintenance are active and the system will react if the operation conditions change. Hence, the operator can easily proceed with troubleshooting the failure, i.e. repairing or replacement of the defective parts with using the code recommended by system and preventive program that is regulated at defined time.

Crossing the breakdown line represents a sudden stoppage of the system working with a high risk percentage. In such circumstances, the end of the life time of the system is probable at any moment; and the event may happen at any unexpected time. In fact, efficiency of machine performance would gradually decline during its working life and this reduction will continue until the process completely stops. If the replacement schedule or prediction stoppage plan has been performed based on these data, sudden stoppages could be prevented and parts can be replaced after working time.

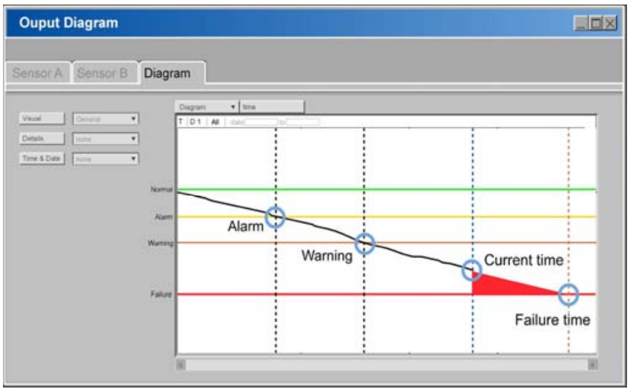

Fig. 8 Diagram of machine life

H. Performance Analysis

Main pump in the filter press works like the mechanism of heart, using wind power. In the event of any disturbances in function of diaphragms, such as minor tears, creation of tiny holes and losing elasticity, the interval between two strokes in pump changes. By supervising this process, we can estimate lifetime of the equipment and diaphragms. The sensors receive the value of vibration in certain timescales which will be analysed in the next process by software. After passing one lifetime, the collected information would be used to analyse when the machine is ready to work at its next lifetime. After determining the alert point, the administrative action will begin in regard with operational decision making.

IV. Conclusion

In this article, a method has been developed in order to increase the application of CBM in an automobile parts manufacturing factory, using a simple and effective software. This method analyzed a real problem and provided an efficient way to achieve clear and understandable idea in order to reduce imposed costs in the maintenance process.

Performing the project at painting line of this factory led to 63% reduction in the costs of unplanned stoppages, costly rework due to the type of operation, production wastage, consuming materials and energy, delivery delay and maintenance costs. Fig. 9 indicates the comparison between the given costs after performing the project in 2011 compared to 2009 and 2010. It should be mentioned that costs of the given project has compensated from expenses which were saved during 2011.

And an empirical study was conducted to consider maintenance position in Iran industries. This research indicated that the role of maintenance is not properly recognized in Iran industries (This is similar to a result published by a previous study in Sweden, see [7]). And also, there is a need to show the role of maintenance in companies' profitability and productivity. FBM is still the most common method in Iran, and based on the answers to the questionnaires, unawareness on the various strategies applied in maintenance process and lack of sufficient training on these strategies could be considered as the most important reasons.

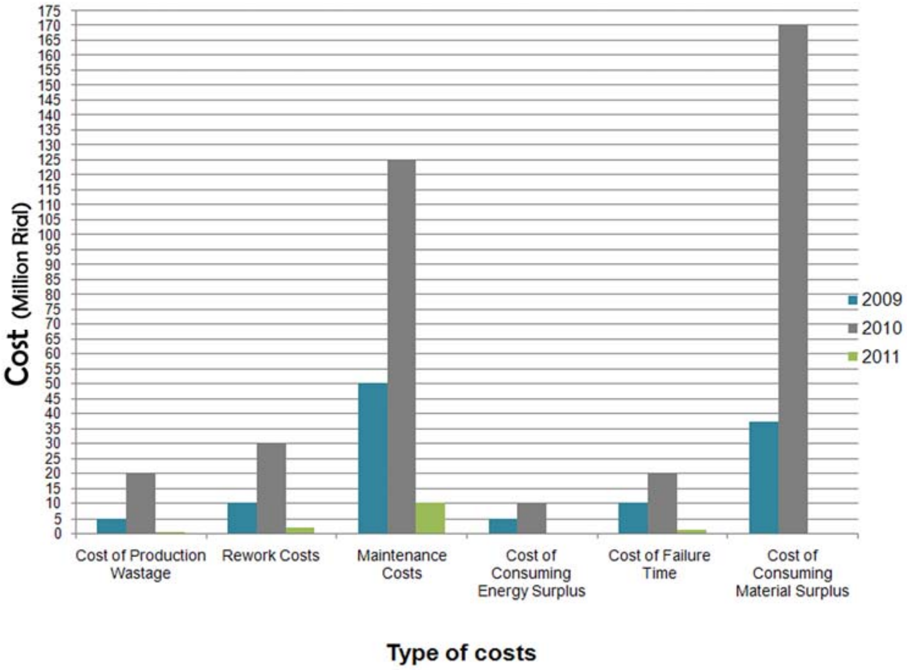

Fig. 9 Comparison between the given costs after performing the project in 2011 compared to 2009 and 2010

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