Programable Automatic Service Time Reminder (PAST-R) To Overcome Traditional Maintenance Approach

Sivaraos, A.R. Samsudin, Tin S.L, A.M Kassim, Taufik, M.A. Amran

Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka
Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka

ARTICLE INFO

Article history:
Received 12 September 2013
Received in revised form 27 October 2013
Accepted 29 October 2013
Available online 18 November 2013

Key words:
Maintenance reminder, service reminder, servicing alert system, rotational counter, microcontroller counter

ABSTRACT

Servicing strategy plays a significant role in avoiding any possible premature machinery failure which could cause major loss of money and human life. However, the present maintenance servicing strategy of today's industry still very much depending on individual experience and traditional monitoring approach always leads to problems, including high frequent failure of machinery, high maintenance expenses and long service cycle. Hence, it is very important to predict the service time and remind the technical personal its time to perform the scheduled service for the machine. In order to increase the flexibility and effectiveness of service reminding in today’s industry, it is here proposed a remote sensing programmable automatic service time reminder (PAST-R) by employing a microcontroller to accurately alert the user via few stages alert system to perform the service as scheduled for respective machines or machine tools. The results of the present investigation show the newly engineered system is very much efficient to minimize not only the down time of the production floor, but also the man-hours to attend the maintenance problems.

INTRODUCTION

Failures of many machinaries faces expensive and far-reaching unexpected consequences. These failures can shut down entire production lines, make buildings unusable, or may also cause major accidents. It is imperative that these types of failures can be prevented. For this reason, a reminding device which alerts the technical assistance to service the machine which needs to be performed more often than is absolutely necessary services to ensure high asset reliability and minimizes unplanned downtime. However, the benefits of this service strategy come with a price. As the machine service incurs costs in both labor and parts, this strategy can result in “over-maintenance”. In addition, service process usually requires assets be taken off-line, which in return incurs cost due to downtime, and lost production. Hence, it is very important that an alert system can precisely assist the user to schedule the most suitable time to perform the service for the machine.

MATERIAL AND METHOD

Theoretical Framework of This Study:

Review of previous works related to services revealed that wear, vibration and temperature were the primary references made to indicate the operating period of a machine is due for the next service. Shore (1972) has presented the prediction and identification of faults in the turbomachinery. Renwick (1984) has presented a condition monitoring program for plant maintenance and diagnosis of heavy machinery problems in which he has discussed the importance of machinery dynamics in the design of a rotating machinery. Kumar et al. (1998) have presented a work using vibration characteristics of a rotor-bearing system, where the condition of a rotating machinery (electrical rotor) is predicted using an off-line expert system. Orhan et al. (2005) claims that, vibration monitoring is suitable for defect diagnosis of rolling element bearings.
The rolling element bearing will produce certain frequencies based on rolling element bearing geometry, shaft speed and number of rolling elements, (see Fig. 1). In order to determine the health condition of the rolling bearing via vibration signal, equation (1)-(4) was successfully employed (Orhan, S., N. Aktuk, V. Celik, 2005)

\[
\alpha = \frac{1 - \cos \alpha}{\frac{D}{2}}
\]

\[
\omega_c = \frac{n \cdot d}{2D} \left[1 - \cos \alpha \right]
\]

\[
\omega_b = \frac{n \cdot d}{2D} \left[1 - \left(\frac{d}{2D}\right)^2 \cos^2 \alpha \right]
\]

\[
\omega_{bp} = \frac{n \cdot N_b \cdot d}{2D} \left[1 - \cos \alpha \right]
\]

\[
\omega_{bpi} = \frac{n \cdot N_b \cdot d}{2D} \left[1 + \cos \alpha \right]
\]

where \(n\), \(N_b\), \(\omega_c\), \(\omega_b\), \(\omega_{bp}\), \(\omega_{bpi}\) represent shaft speed, number of rolling elements, cage frequency, rolling element spin frequency, rolling element pass frequency outer race, rolling element pass frequency inner race.

Wang et al. (2010) designed a realization of a remote monitoring diagnosis and prediction system for large rotating machinery.

This remote monitoring system is installed for the flue gas turbine to monitor the health condition of the machine through shaft vibration and displacement, shaft speed and bearing brush temperature. Fig 2 indicates the monitoring page for the unit outline diagram, which displays the physical outline diagram of the gas turbine. For the more recent, Scanlon et al. (2013) predict the remaining useful life of rotating machine by using acoustic noise signal (<25 kHz) via non-contact microphone sensors. Fig. 3 shows the rotating machine being monitored; the acoustic signal generated by the machine is captured by the suitably placed microphone sensor. This analog signal
will be then converted into digital signal using an ADC. The digital signal is used to classify the health level of the machine by the monitoring system.

Fig. 3: Automated monitoring system architecture including acoustic signal acquisition, feature extraction, classifier training, and testing. (Patricia Scanlon et al., 2013)

The critical review found that the available solutions could be further improved as they lack in detecting accuracy and may not exactly suitable as far as the flexibility and cost effectiveness are concern. This including of those service time scheduling of rotating machine which were suggested via operating time counting by several industries and researchers (SKF General Catalogue, 2003; ROTOPRECISION INC 2012; Herbert, W., 2011; Bark, H.E., et al., 2009; Krejcar, O., et al., 2011; Jaanus, M., et al., 2013). In this research, a programmable automatic service time reminder by using microcontroller is proposed, which is the widely used modern electronic component due to the precision in signal processing and the flexibility in programming. This system is able in measuring machine’s workload via remote sensing and count down the remaining time for the machine before its due for the next service. As to test the operating accuracy and reliability, the system was tested in the monitoring of the total amount of operating journal bearing life cycle of a rotary loaded shaft. The repetitive experiments validated that, the established system is highly capable to predict the remaining lifespan of the journal bearing and precisely alert the technical team in stages for them to adversely prepare servicing schedule including necessary tools and manpower to perform the task timely which will tremendously reduce the down time and lead time of the production line due to service breakdown.

**Design Outline of PAST-R:**

Fig. 4. illustrates a block diagram of the developed programmable service time counter system towards generating an output signal at the expiration of a preselected total operating time in conventional industrial equipment or rotating machinery such as the bearing system. The programmable time counter system is generally designated by using PIC16F877A reference numeral 3 and receives an input signal from an inductive magnetic sensor 1 via line 2. It is also connected to indicator light and buzzer by reference numeral 5 via line 4. A power source 6 has its output applied to the counter system via line 7. The power source 6 delivers a +6 VDC on its output lines.

Fig. 4: Overall block diagram of the programmable service time reminder counter system
**Machine Rotational Speed Determination:**

Initially, one of the input port of the microcontroller set as digital input. When the inductive magnetic sensor detects the existence of the metal on shaft, it will produce a output voltage. Since the shaft is rotating, the sensor produces the output voltage as pulse signal. This pulse signal will trigger the digital input port of microcontroller and the microcontroller is able to determine the rotation speed (Stojkovic, N., Z. Stare, N. Mijat, 2001) of the machine by measuring frequency method, which is based on the number of pulse counted in a fixed time window. Eq. (5) is applied to calculate the rotation speed.

\[
 n = \frac{N \times 60}{T_w} \text{ (rpm)}
\]

Where:
- \( n \) = machine rotation speed
- \( N \) = number of pulse measured within time window
- \( T_w \) = time window

**Timer System Architecture:**

Based on the operational architecture shown in Fig. 5, the timer will start counting once the inductive metal sensor detects the shaft is rotating. The magnetic signal allows the sensor to send signal to the microcontroller for counting purposes. The timer will then start counting down. Once the remaining operating time reaches the first warning figure as set in the microcontroller, the yellow indicator light will ON and buzzer will sound in lower frequency as a first warning to the user to carry out maintenance. The timer will continue to count down until the remaining operating time reaches zero if the rotation device is still continuing operating without any performance for the maintenance purpose. Once the operating time reaches zero, the red indicator will ON and the buzzer will sound in higher frequency as a serious warning sign until the maintenance is performed.

![Fig. 5: The overall system operation flowchart](image)

**Bearing Life Determination:**

The calculation of bearing life can be very challenging and confusing as there are multiple equations which are based on different factors resulting in different values. Understanding the result calculated and how the equation works are important to decide whether the bearing still work in a health condition or not. These values
are also possible to be attained from bearing handbook correlated with loading type. Thus, the most widely used and acceptable equation for calculating the bearing life is known as bearing life rating equation. The bearing rating life ($L_{10}$) is defined as the life in operating time in hours that 90% of a group of apparently identical bearings will complete or exceed. It can be expressed through the following equation (6).

$$L_{10} = \left( \frac{C_r}{P_r} \right)^p \times \frac{10^6}{60n}$$

(6)

Where:

- $L_{10}$ = The expected bearing rating life at 90% reliability (hours)
- $C_r$ = Dynamic Load Rating (kN)
- $P_r$ = Dynamic Equivalent Radial Load (kN)
- $n$ = Machine rotation speed (rpm)
- $p$ = Life exponent

- For Ball bearing, use 3.
- For Roller bearing, use 10/3.

Equation (6) is in accordance to the ISO 281:1990 standard. As mentioned previously, the result of the bearing life calculation can be affected by additional factors too. Some of those factors are including reliability factors, viscosity ratios, contamination factors, material characteristics, and lubrication factors. These factors will play a role when using equations known as the adjusted rating life equation, expanded adjusted rating life, or the new life theory. However, these adjusted rating life equations are not covered in this paper.

**Experimental Setup:**

Fig. 6: Equipment configuration for the experiment

Fig. 6 shows the equipment configuration for the accuracy validation experiment for the rotation counter. An electrical motor was used to drive the shaft at constant rotational speed of 2130 RPM. The selected inductive magnetic sensor was used to detect the mating point of rotary and static points to create a magnetic signal. The initial total operating time was set for 10 minutes as it was to rotate 21300 revolutions at 2130 RPM to ease theoretical analysis. The remaining operating time was then shown on the LCD display panel which can be recorded for each minute, where 10 samplings will be obtained in 10 minutes. The results from the counter was then compared to the results from theoretical calculations. This set of experiments was repetitively performed to validate the reliability and accuracy of the established system error percentage (%), average error percentage (%), system accuracy (%), average system accuracy (%) was obtained via Eq. (7)-(10):

$$\text{Error Percentage (\%)} = \frac{\text{TIME (Theoretical)} - \text{TIME (Counter)}}{\text{TIME (Theoretical)}} \times 100\%$$

(6)
RESULT AND DISCUSSION

Table 1: Observed result of accuracy validation experiment

<table>
<thead>
<tr>
<th>Revolution</th>
<th>Remaining TIME (Timer)</th>
<th>Remaining TIME (theoretical)</th>
<th>Error (%)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>2130</td>
<td>9.0623</td>
<td>9</td>
<td>0.23</td>
<td>99.77</td>
</tr>
<tr>
<td>4290</td>
<td>8.0046</td>
<td>8</td>
<td>0.23</td>
<td>99.77</td>
</tr>
<tr>
<td>6590</td>
<td>7.0102</td>
<td>7</td>
<td>0.56</td>
<td>99.44</td>
</tr>
<tr>
<td>8520</td>
<td>6.0172</td>
<td>6</td>
<td>0.70</td>
<td>99.30</td>
</tr>
<tr>
<td>10650</td>
<td>5.0241</td>
<td>5</td>
<td>0.89</td>
<td>99.11</td>
</tr>
<tr>
<td>12780</td>
<td>4.0350</td>
<td>4</td>
<td>0.89</td>
<td>99.11</td>
</tr>
<tr>
<td>14910</td>
<td>3.0453</td>
<td>3</td>
<td>1.03</td>
<td>98.97</td>
</tr>
<tr>
<td>17040</td>
<td>2.0565</td>
<td>2</td>
<td>1.12</td>
<td>98.88</td>
</tr>
<tr>
<td>19170</td>
<td>1.0698</td>
<td>1</td>
<td>1.31</td>
<td>98.69</td>
</tr>
<tr>
<td>21300</td>
<td>0.0827</td>
<td>0</td>
<td>1.31</td>
<td>98.69</td>
</tr>
<tr>
<td>Average (%)</td>
<td></td>
<td></td>
<td>0.83</td>
<td>99.17</td>
</tr>
</tbody>
</table>

Table 1 shows the average values of experimental observed results. The established system has been experimentally validated to have more than 99% of detection accuracy proving the reliability of the system to be employed into the real industrial scenario. This result shows that the estimation of the machine work via wireless monitoring using the induction sensor is very direct and simple, yet able to solve ample problems faced by industries especially on rotational machineries and equipments. Not only that, this approach provides a very cost effective solution as compared to some expensive systems which were intended to alarm the servicing peak time. The established system is also very flexible to be operated and installation, where not only it is very direct and simple, but can also be reconfigured by almost anybody without having any prior programming skills.

Conclusion:
An accurate, cost effective and flexible service time reminder have been designed in a simplified manner yet able to perform as intended to overcome challenges of few available solutions in the market. After a series of experimental validation, this system is proven to be highly potential for practical applications of the world wide industries to machineries are attained for services timely as per required or scheduled without any human error/over look problem towards avoiding sudden machinery failure which would lead into terrible unexpected industrial loses and expenses.

ACKNOWLEDGEMENT

First and foremost, the authors would like to thank Universiti Teknikal Malaysia Melaka and Ministry of Higher Education Malaysia for providing financial support by awarding research grants (Grant number: PJP/2012/FKP(9C)/S01012, and GLuar/2012/FKP(1)/G00010) which succeeded this research work. Authors are also in debt to specially thank the top level management of Universiti Teknikal Malaysia Melaka, Centre for Research and Innovation Management, and Faculty of Manufacturing Engineering administrators for their continuous courage and support which brought this research work to a successful findings benefiting industries and mankind.

REFERENCES

Herbert, W., 2011. “Rolling Element Bearing Basics In Large Electric Motors”, Pulp And Paper Industry
ROTOPRECISION INC. Catalogue, 2012
SKF General Catalogue, Catalogue 5000E June 2003