International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Review Article

Spindle Digitization: A Review

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Received 02 Dec 2018, Accepted 03 Feb 2019, Available online 05 Feb 2019, **Vol.9, No.1 (Jan/Feb 2019)**

Abstract

Spindles are the integral part of any rotating machine. Any deterioration of spindle performance will lead to the manufacturing of faulty products. Maintenance can prevent rapid deterioration of spindles but unnecessary and untimely maintenance leads to increase in cost and machine downtime leading to losses. This paper focuses on Condition Based Monitoring of spindle units. CBM includes techniques such as vibration and temperature monitoring. This allows us to predict the failure of spindles and take preventive actions. This also prevents any catastrophic failures.

Keywords: *Condition Based Monitoring, Preventive Maintenance*

1. Introduction

Due to ever increasing demands of our society the current manufacturing facilities are pushed to their maximum limits. Factories are operating day and night for the whole year to meet their delivery schedules. This means long operating hours and minimal maintenance. This puts a lot of pressure on the machines producing or shaping the products. The heart of any rotating machine is the spindle. Any damage to the spindle leads to the complete breakdown of the machine and manufacturing process. This has created the need for modernization and optimization of performance of machine spindles to keep up with ever increasing demands. Research is necessary to track the health of these spindles and to prevent catastrophic breakdowns. One of the methods of monitoring the health of the spindles is by tracking their operating temperature and vibrations produced during machining. Every rotating component produces its own distinct vibrations at a fixed frequency. This frequency may vary during the machining process. If we can monitor this frequency, then it is possible to estimate the failure point of that particular spindle.

2. Condition Based Monitoring

CBM is a maintenance strategy that monitors the actual condition of the system to decide if maintenance needs to be done and exactly which maintenance is required. According to CBM maintenance should only be performed when certain components show signs of decreasing performance or upcoming failure. CBM monitoring generally consists of techniques which do not require a halt of production process. Condition data can be gathered at regular intervals or continuously (when sensors are placed internally). In planned maintenance, maintenance is performed at predefined intervals even if it is not required. This leads to a lot of downtime and production delays.

3. Effect of Vibrations on Machine Elements

Vibrations are inherent in machine systems. Every machine component vibrates within a set of frequency limits. In some cases, vibration is essential as in case of tumblers or oscillating sanders. Vibrations become a problem when they exceed their acceptable limits. They can cause improper surface finish in products or cause excess wear in casings of machines. It can also lead to overheating and if it's a high speed machine then it can cause a lot of damage if a nut or bolt goes flying out. (Vibration analysis of machine tool spindle units , 2017)

Refer Table.1 for the preferred method to implement vibration analysis for spindle digitization. It gives the correct way to obtain error free measurement and to get the data without any error due to external factors.

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DOI: https://doi.org/10.14741/ijcet/v.9.1.8

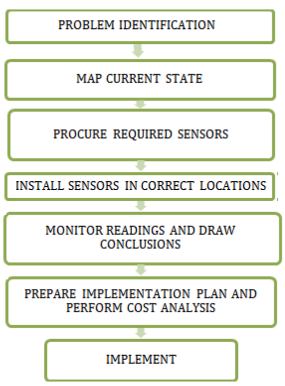
Table.1 Implementation Factors for Vibration Measurement

Sr.No	Implementation Factor	Explanation
1	Sensor Type	Vibration sensor with sensitivity of 100mV/g for spindles with operating speed between 60 to 30,000 rpm
2	Sensor Location	In radial and axial direction at front and back end of spindles as close to bearings as possible
3	Machine loading condition	No loading condition
4	Rotational speed	The machines operation speed
5	Measurement Frequency	Varies with spindle type and bearing types
6	Automatic or handheld measurement	Using handheld or on-line inspection
7	Alert and alarm limits	As required
8	Measurement Interval	Depends on criticality of machine

4. Experimental Setup

1) Problem Identification: - Before any optimization process is done the problem statement should be defined
2) Study and map the current setup: - Identify critical components and decide which parameters are important
3) Procure the required sensors: - Correct sensor procurement is important. Correct sensor type should be selected. Sensors of correct sensitivity, accuracy and range should be selected.
   a. E.g. Inductive type of sensors should be used instead of Capacitive if there is presence of small suspended particles in air surrounding the sensor as this will trigger the capacitive ones unnecessarily.
4) Install sensors in correct location: - Placement of sensors plays an important role in determining its accuracy. E.g.: - if we place a magnetic sensor near a magnetic field then it will give wrong readings due to presence of magnetic field.
5) Monitor the readings and draw suitable conclusions
6) Prepare implementation plan and perform feasibility analysis.
7) Implement the suggestions to improve efficiency and reduce downtime.

5. Flowchart of Experimental Setup



6. Experimental Results

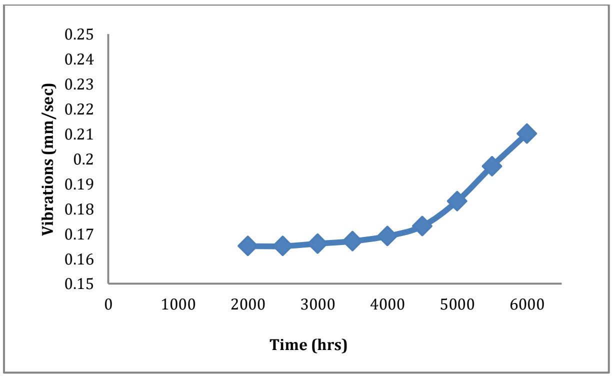
To plan the preventive maintenance, spindle vibrations of CNC machine were monitored and reliability of the system was calculated at no load conditions and at varying speeds for varying operating hours. Analysis was done at speeds of 500, 1000, 1500 and 2000rpm. The working hours were considered between 2000 hours to 6000 hours in steps of 500 hours. (Life Prediction of a Spindle CNC Machining Centre Using Natural Frequency Method of Vibration, 2015)

Table 2 Vibrations (mm/sec) for No Load for Different Working Hours

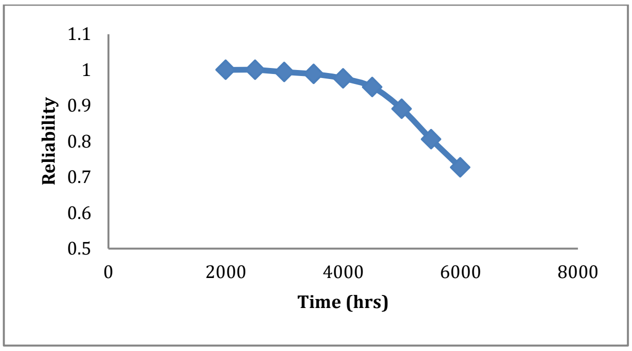
Spindle Speed (rpm)	500	1000	1500	2000
Time				
2000 hrs	0.165	0.169	0.183	0.158
2500 hrs	0.165	0.169	0.183	0.163
3000 hrs	0.166	0.169	0.184	0.166
3500 hrs	0.167	0.171	0.187	0.167
4000 hrs	0.169	0.175	0.189	0.169
4500 hrs	0.171	0.181	0.19	0.173
5000 hrs	0.183	0.185	0.227	0.183
5500 hrs	0.197	0.2	0.25	0.187
6000 hrs	0.21	0.22	0.25	0.19

Table 3: Reliability for overall vibration at each speed

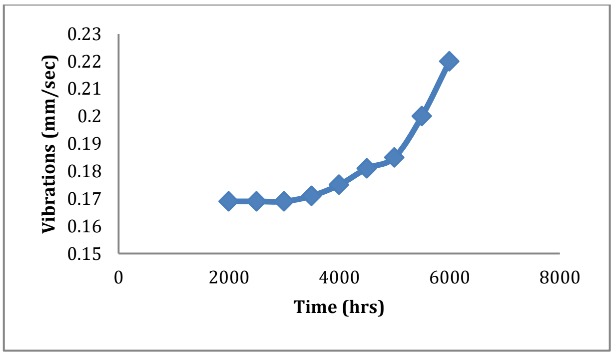
Spindle Speed (rpm)	500	1000	1500	2000
Time				
2000 hrs	1	1	1	1
2500 hrs	1	1	1	0.968
3000 hrs	0.994	1	0.995	0.949
3500 hrs	0.988	0.988	0.978	0.943
4000 hrs	0.976	0.964	0.967	0.93
4500 hrs	0.952	0.929	0.962	0.905
5000 hrs	0.891	0.905	0.76	0.842
5500 hrs	0.806	0.817	0.634	0.816
6000 hrs	0.727	0.698	0.634	0.797



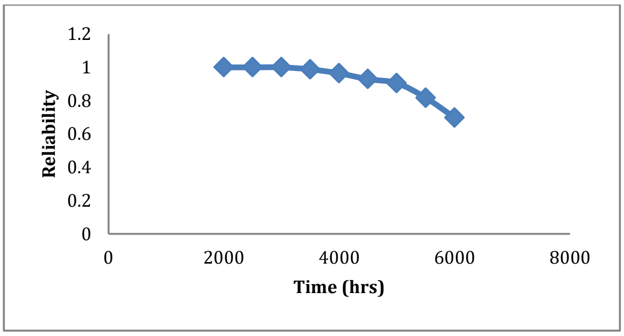
Graph 1: - Vibrations vs Time (500 rpm)



Graph 2: Reliability vs Time (500 rpm)

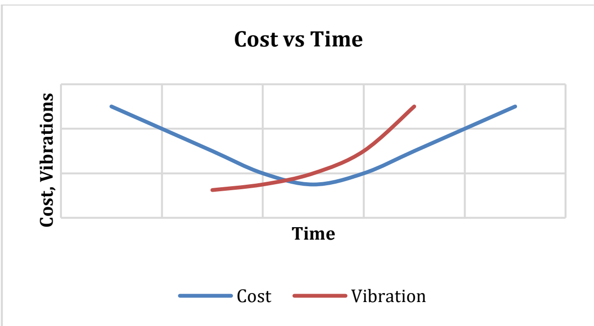


Graph 3: Vibrations vs Time (1000 rpm)



Graph 4: Reliability vs Time (1000 rpm)

It was observed that vibrations increase exponentially after some time and reliability decreases exponentially. However, changing spindles regularly will lead to huge cost increases and is economically unviable. (Life Prediction of a Spindle CNC Machining Centre Using Natural Frequency Method of Vibration, 2015)



Graph 5: Cost Vs Time

The cost of running the machines is represented by the exponential curve.

1) It is high initially as it represents cost of changing spindles or other components regularly.
2) Later on it again increases as it represents the losses due to low quality. This also represents losses due to loss of customers.
3) Hence maintenance should be done in the ideal region as this would reduce losses due to other factors and lead to more machine uptime.

7. Cost Effectiveness of Spindle Digitalization

1) Let us assume that a company is manufacturing a component and is experiencing quality issues.
2) Every time this problem arises production is stopped and machines are inspected. This leads to loss in production hours.
3) Also minor components of the machine are replaced which solves the problem temporarily. However, the root cause of the problem is not solved. When vibration analysis was performed it was determined that the spindle needed to be replaced.
4) Replacing the spindle takes lesser time and is less costly when compared to loss in production and loss due to frequent changing of components. Frequent stops in production also lead to delivery delays, this leads to customer dissatisfaction leading to loss of customer base. (Vibration analysis of machine tool spindle units , 2017)

8. Suggested Applications

Digitization of spindles can be used in high precession spindles where performance is crucial and any breakdown can lead to huge losses. They include:

1) Production
2) Optical
3) Dental
4) Robot Applications etc.

Conclusion

From above research and experimentation, we can conclude that spindle digitalization has following advantages:

1) Reduced safety issues
2) Reduced scrap
3) Reduction in spares storage and cost
4) Reduced machine downtime
5) Easy planning of maintenance

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