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Study of In-Situ Dynamic Balancing of Spindle-Chuck Assembly of CNC Lathe

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Abstract - The motorized spindle plays an important role in high-speed machining. The level and performance of CNC machine tool are decided and evaluated by a technology level of motorized spindle and its performance. Then it is necessary and significant to find efficient and convenient ways for the research of motorized spindle. The machine spindle system is one of the most important parts of a machine tool since its dynamic properties directly affect the cutting ability of the machine tool. The dimensions of the spindle shaft, location, stiffness of the bearings and bearing preload affect the vibration free operation of the spindle. Angular contact ball bearings are most commonly used in high-speed spindles due to their low-friction properties and ability to withstand external loads in both axial and radial directions.

Keywords - CNC Headstock spindle, Dynamic balancing, FFT Analyzer, Vibration severity level.

I. INTRODUCTION

The CNC system has played a key role in making of the modern automation systems and as such, rapid progress has been made in this field. The introduction of CNC machines has made it possible to produce products of repeatable consistent quality, apart from enabling the industry to optimize productivity with a high degree of flexibility in production batches. The design and construction of Computer Numerically Controlled (CNC) machines differs greatly from that of conventional machine tools. This difference arises from the requirements of higher performance levels. The CNC machines often employ the various mechatronics elements that have been developed over the years. However, the quality and reliability of these machines depends on the various machine elements and subsystems of the machines.

Fig. 1 : Headstock spindle assembly of Ultra C-300 series CNC lathe machine

The spindle of CNC Lathe machine is located in the headstock of the machine and is supported by two set of angular contact ball bearings as shown in figure 1 which allow high speed operation.

The bearings once lubricated can be made to run for long period. The front set of bearings contain three angular contact ball bearings and secured by means of an adjustable locknut. The rear set of two angular contact ball bearings is secured on the spindle along with the bearing spacer and sprockets by means of rear adjustable locknut. A threaded area and the keyway are provided on the end of the spindle for mounting work holding equipment.

II. IN-SITU DYNAMIC BALANCING

A new machine when assembled at its permanent location will need balancing or a machine already in operation will need re-balancing. Some common causes of irregularity during production are machining error, cumulative assembly tolerances. Because of these irregularities the actual axis of rotation does not coincide with one of the principal axes of inertia of the body and variable disturbing forces are produced which result in vibrations. In order to remove these vibrations and establish proper operation balancing becomes necessary. Therefore, the balancing of high-speed equipment is especially important.

The system of balancing used in this experiment is to perform field balancing of headstock spindle assembly of CNC lathe machine by making use of DI 440 FFT analyzer and other balancing accessories. Although there are many possible causes of vibration in rotating equipment, this technique will deal only with that caused by the mass unbalance. For a rigid long rotor, the unbalance can be in different axial planes. As a result, while in rotation the unbalanced forces form a couple and a lateral force, which rocks the axis of rotation and causes undesirable vibration of the rotor, mounted in its bearings. It can be shown that for the correct balance of such a rotor, two masses placed in different radial planes of the rotor are necessary and sufficient to balance the rotor. There are the amount and position of these two correction masses to be dealt with when balancing any rigid rotor. The data necessary to determine the magnitudes and position (angle) of the two correction masses are obtained by test runs at the same speed. The vibration amplitude and phase angle are measured by each proximity probe. An important assumption made by this technique is that the system follows linear relationships i.e., the vibration amplitude is proportional to the force producing the vibration. This assumption is reasonably valid.

III. INSTRUMENTS USED

DI 440 FFT analyzer , Accelerometer, Tachometer probe and Tachometer module , Other balancing accessories.

IV. ARRANGEMENT OF INSTRUMENTATION TO MEASURE VIBRATION SEVERITY LEVEL

The motion (or dynamic force) of the vibrating body is converted in to electrical signal by the vibration transducer or pickup. In general, a transducer is a device that transforms changes in mechanical quantities (such as displacement, velocity, acceleration, or force) into changes in electrical quantities (such as voltage or current). Since the output of a transducer is too small to be recorded directly, a signal conversion instrument is used to amplify the signal to the required value. The output from the signal conversion instrument can be presented on a display unit for visual inspection, or recorded by a rotating unit or stored in a computer for later use. The data can be analyzed to determine the desired vibration characteristics of the machine.

V. CHECKING OF VIBRATION SEVERITY LEVELS

A. Case 1

Fig. 2 Location of vibration transducer near sprocket end

In figure 2 the vibration transducer is mounted near the sprocket end to which the motor is connected through T-belt for transmission of rotational motion to spindle assembly. Measurement of vibration severity level at motor drive end (for both before balancing and after balancing) conditions are carried out by running the spindle between the speed limits of 400 rpm to 6000 rpm as shown in Table 1.

Table1. Vibration severity levels of Motor drive end

Measure ment point	Speed in rpm	Vibration severity level in mm/sec (rms.)		Correction in gm-mm
		Before balancing	After balancing	
Motor drive end	400	0.096	0.025	2400
	800	0.147	0.070	
	1200	0.176	0.094	
	1600	0.178	0.112	
	2000	0.267	0.128	
	2400	0.328	0.190	
	2800	0.382	0.241	
	3200	0.343	0.211	
	3600	0.369	0.231	
	4000	0.408	0.241	
	4400	0.469	0.252	
	4800	0.550	0.245	
	5200	0.647	0.248	
	5600	0.773	0.238	
	6000	1.201	0.275

Fig. 3 Vibration severity levels at motor drive end

The variation of vibration severity levels v/s spindle speed at motor drive end (for both before and after balancing cases) is shown graphically in Figure 3. By running the spindle between the speed limits of 400 rpm to 6000 rpm, the vibration severity level at the measurement point- motor drive end seems to be out of range as per ISO 10816, thus on undergoing the correction of 2400 gm-mm, the vibration severity level has reached the specified range which is pertaining to class 1 of industrial standard as per ISO 10816.

B. Case-II:

Fig. 4 Location of vibration transducer at both spindle front and rear end

The arrangement of vibration transducer at spindle front and rear end is shown in figure 4. Measurement of vibration severity level for the spindle without chuck and cylinder at both spindle front and rear end locations are carried out by running the spindle between the speed limits of 200 rpm to 3000 rpm as shown in Table 2

Table 2 Vibration severity levels of spindle without chuck and cylinder

Measure ment point	Speed in rpm	Vibration severity level in mm/sec (rms)			
		Before balancing		After balancing	
		Sp[F]	Sp[R]	Sp[F]	Sp[R]
Spindle without chuck and cylinder	200	0.012	0.015	0.003	0.004
	400	0.016	0.019	0.006	0.006
	600	0.022	0.020	0.005	0.007
	800	0.032	0.025	0.011	0.009
	1000	0.083	0.077	0.016	0.011
	1200	0.042	0.045	0.008	0.009
	1400	0.087	0.100	0.028	0.022
	1600	0.153	0.189	0.032	0.021
	1800	0.424	0.496	0.072	0.063
	2000	0.416	0.484	0.055	0.033
	2200	0.309	0.374	0.059	0.054
	2400	0.303	0.371	0.047	0.063
	2600	0.348	0.410	0.056	0.078
	2800	0.334	0.406	0.039	0.092
	3000	0.265	0.324	0.025	0.086

Correction in gm-mm = 3750

as per ISO 10816. Thus by undergoing the correction of 3750gm-mm, the vibration severity level has reached the specified range by undergoing the correction which is pertaining to class 1 of industrial standard as per ISO 10816.

The variation of vibration severity levels v/s spindle speed before balancing of the spindle (without chuck and cylinder) at both spindle front and rear end locations is shown graphically in Figure 5. Whereas the plot shown in Figure 6 gives the graphical variation of vibration severity levels v/s spindle speed after balancing of the spindle (without chuck and cylinder) at both spindle front and rear end locations.

Fig. 5 Vibration severity levels of spindle without chuck and cylinder (Before balancing)

Fig. 6 Vibration severity levels of spindle without chuck and cylinder (After balancing)

By running the spindle from 200rpm to 3000 rpm, the vibration severity level at the measurement point: spindle without chuck and cylinder seems to be out of range. Measurement of vibration severity level for the spindle assembly (with chuck and cylinder) at both spindle front and rear end locations are carried out by running the spindle between the speed limits of 200 rpm to 1600 rpm as shown in Table 3.

Table 3 Vibration severity levels of spindle with chuck and cylinder

Meas urem ent point	Spee d in rpm	Vibration severity level in mm/sec (rms.)				Corr ectio n in gm- mm
Spin dle with chuc k and cylin der		Before balancing		After balancing		No corr ection requi red
		Sp[F]	Sp[R]	Sp[F]	Sp[R]	
	200	0.009	0.008	-	-	
	400	0.012	0.010	-	-	
	600	0.011	0.012	-	-	
	800	0.045	0.039	-	-	
	1000	0.069	0.085	-	-	
	1200	0.091	0.105	-	-	
	1400	0.111	0.129	-	-	
	1600	0.215	0.226	-	-	

C. Case-III:

Fig. 6 Location of vibration transducer at both spindle front and rear end

Fig. 7 Vibration severity levels of spindle with chuck and cylinder

The arrangement of vibration transducer at both spindle front and rear end is shown in figure 6. The variation of vibration severity levels v/s spindle speed for the spindle assembly (with chuck and cylinder) at both spindle front and rear end locations is shown graphically in figure 7. By running the spindle from 200 rpm to 1600 rpm, the vibration severity level at the measurement point: Spindle with chuck and cylinder seems to vary within the range as per the industrial standard ISO 10816 which is pertaining to class 1. Thus as the spindle assembly is balanced before balancing as per the ISO 10816 standards, there is no necessity of undergoing correction of masses for the above said case.

VI. CONCLUSION

- The mass correction effected on the Motor-spindle assembly for the purpose of unbalance correction should not be altered in any manner. Doing so would alter the balance quality achieved.
- Any change/alteration in the rotating mass of Motor-spindle assembly will change the balance quality achieved.
- ISO 10816 Vibration severity chart (mm/sec RMS velocity vibration) is given in table 4.

Table 4 ISO 10816 Vibration severity chart (mm/sec RMS velocity vibration)

	GOOD	PERMISSIBLE	STILL PERMISSIBLE	DANGEROUS
CLASS 1	0.28-0.7	0.7-1.8	1.8-4.5	4.5 and above
CLASS 2	0.28-1.2	1.2-2.8	2.8-7.1	4.5 and above
CLASS 3	0.28-1.8	1.8-4.5	4.5-11.2	4.5 and above
CLASS 4	0.28-2.8	2.8-7.1	7.1-18.0	4.5 and above

- Class 1: Small precision machines especially production machines up to 15 kW (20HP).
- Class 2: Medium machines 15 kW to 75 kW (20 HP to 100 HP) without special Foundations
- Class 3: Large machines with heavy foundations
- Class 4: Largest machines and heavy machines with special foundations.

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