Monitor System Design for Machine Electric Spindle based on MCGS

Xue Yangang, Wang Han, Luo Xingqi
Institute of Water Resources and Hydro-electric Engineering
Xi’an University of Technology
Xi’an, China
Email: xyg3024_cn@163.com

He Qiang
Institute of Mechanical Engineering
Institute of Anyang
Henan, China
Email: hwang_spirit@126.com

Abstract—This article introduces some principal parameters, which are required to be monitored, of machine electric spindle, hardware components of the system and main functions of configuration software MCGS (Monitor and Control Generated System) in China. The system is a set of online monitoring and analysis system that is designed for machine electric spindle. The system analyzes real-time information acquired from the vibration of machine electric spindle, the rotational speed, the motor, the temperature between front and back bearing, the axial displacement and relative parameters. It can provide information for workers who are not familiar with spindle to recognize spindle condition or discover early fault information, thus it eliminates malfunction and avoids destructive accidents. It also can offer technical information, such as machine electric spindle optimum design and test.

Keywords—configuration software; sensor; Online monitoring; electric spindle;

I. INTRODUCTION

Monitor machine is becoming more and more important with the development of CNC in China [1]. Machine electric spindle is one of important function components, the condition affect machine’s capability. Vibration is caused during machine is on operation which has deficiencies in mechanism, manufacture and installation on rotor, customers, bearing seal in spindle [2-4]. Oversized vibration is the main problem that cause machine fault. We need monitor and analyze some principal parameters for keep machine in good condition or could be quick mended. Recently, online monitor and diagnose operation condition of spindle is becoming necessary with the exploitation of software and development of monitor theory. Intelligent monitor manage monitor electric spindle and expert system according workers demand [5]. Due to the remarkable tribological properties of nanoparticles, good environmental-friendly property, Nanotechnology is regarded as the most revolutionary technology of the 21st century. nanoparticles have been desired for an excellent candidate instead traditional lubricant additives, especially at severe frictional conditions, such as high load and high sliding speed, high temperature. Numerous nanoparticles used as oil additives have been investigated in recent years. Among those which as base oil additives, Cu nanoparticles have received much attention and exhibited excellent applications because they deposit on the rubbing surface and improve the tribological properties of the base oil, displaying good antifriction and wear reduction characteristics. Furthermore, although considerable efforts have been made to understand how Cu nanoparticles work as additives in oil to reduce friction and wear, their mechanism is still not very clear some scholars regard Cu nanoparticles near sphericity, it play a role of miniature “ball bearing”. For the ball bearing mechanism, researchers consider it still as an assumption without direct experimental evidence due to the deficiency of in suited characterization method. The bearing must be replaced after wear and tear. There are Some influencing factors, such as the concentration of Cu nanoparticles in based oil, sliding speed, applied load, to affecting the lubrication effect. The author used four ball machine To finding the best Cu nanoparticle concentration in N32 base oil. If Cu nanoparticles as N32 base oil additive can improve the work life of the bearing, it will have important influence on machinery industry.

II. MONITOR ON PRINCIPAL PARAMETERS

With the CNC (Computerized Numerical Control) electric spindle becoming speed up, more efficiency, huge-capacity, huge-torque and high reliability, we need high level accuracy monitor spindle to know its condition exactly according monitor dates [6-10]. These principal parameters are:

1. Amplitude: deviate balance position, describe the scale of vibration. As well as an important index to indicate vibration with displace, velocity and acceleration. Vibration of spindle...
always in a range steadily, huge changing of amplitude describe that the operating state of spindle have been changed, so it is clear to determine whether the equipment is stable running through monitoring the amplitude [11,12].

2. Frequency: an important parameter to distinguish vibration form because of their relationship is integer multiples or fraction. Phase is an important parameter. First Peak Force is relative to the high position of rotor with that to make fix about balance and uncounterbalanced’s position, these are main basis to spindle balance.

3. Vibration Form: original vibration waveform that displayed on oscillograph is a very important way to analyze vibration dates. Eddy current sensor with 90 degree between each other that fixed on machine can good describe vibration form. There are two ways of vibration form: 1) time base-Waveform and 2) Shaft Centerline Orbit [13-15]. We can definite amplitude, frequency and phase with time base-Waveform. We can observe spindle’s movement with Shaft Centerline Orbit.

4. Axial shifts: the main purpose is to make sure axial clearance between rotor and stator, to avoid axial friction. And reference when analyze vibration with radial vibration data [16-19].

5. Rotating speed: Improve the electro-spindle rotating speed can increase the efficiency of their work, but then the speed is too high would cause the vibration of spindle. The operating speed of the spindle should be to avoid the critical resonance speed for averting that the spindle critical working states appear the rotating speed is an important parameter for vibration of equipment [20-23].

6. Temperatures: Intense frictional heat and high-frequency electric heat of Spindle bearing in high speed can make it hot deformation. Too high temperature is injuring to electric spindle, we need to monitor it. There are two ways with electric spindle: 1) built-in motor heat and, 2) Spindle bearing heat. To find out the temperature change in spindle, engineering usually make periphery of spindle fore bearing as representative region to measure system temperature [24]. Fig.1 shows measuring points on electric spindle.

III. COMPONENTS OF SYSTEM HARDWARE

System hardware is made of temperature sensor; rotate speed sensor, vibration sensor, shift sensor, signal transmitter according practical situation and objective of study. The structure of system is as follow in Fig.2:

![Figure 1. The measuring point on electric spindle.](image)

![Figure 2. Components of system hardware.](image)

The temperature of motor and spindle is measured with PT100 platinum resistance which is a temperature sensor. And collect signal with PT100 and PLC together can eliminate Temperature Transmitter to reduce cost and easy to maintain. While notching place passes front-end of hall-effect sensor, speed sensor using Hall Effect causes changes of the magnetic field. The hall component detects changes of the magnetic field and converts it to an alternating signal. The built-in circuit amplifies and rectifies the signal to output the good rectangular pulse signal. It makes the measuring frequency wider, the output signal more precise and the installation easier.

Both vibration and axis shift sensor use eddy current sensor which component oscillator with pre-device. Amplitude attenuates when sensor probe and metallic getting closer, the attenuation is in direct proportion to distance between sensor and metallic. The following are some simple principles for installation eddy current sensor: 1) cut holes according electric spindle size, 2) sensor probe runs parallel with principal axis, 3) the area of spindle is one and a half times greater than area of sensor, 4) there should be no high magnetic fields around sensors, 5) try to decrease the length of extending cable.

Extension module use SM331 version of Siemens S7-300 and can connect with PT100 directly make it has high performance price ratio. The extension module connect PLC controller through core bus, read data with CPU. Therefore, it has more precision than others.

Controller use S7-300. It’s network connections is relatively perfect and popular, make communication and coding more easier and multi-selection with MPI(multi point interface), can configuration and set parameters with Hardware configuration.

Pump controller is to adjust inflow with temperature sensor and expert system to reduce the temperature of spindle reasonable. Air-Oil controller, Air-Oil Lubrication Technology use compressed air to supply each spindle bearing with lubricant continuously, respectively and accurately. Small oil droplets formed into elastic dynamic pressure oil film between the roll and the internal and external raceway, and the compressed air can take away heat predicted by the bearing running. Air-Oil controller is used to control oil and gas content in terms of the lubrication condition of bearing. Practice showed that to supply too much or too little lubricating oil are all harmful through the greasing.
IV. SYSTEM SOFTWARE

MCGS (Monitor and Control Generated System) is a set of configuration software used for fast construction and generation of monitoring signals. Through collecting and processing field data, it offers customers solutions for engineering problems by means of animation display, alarm processing, process control, real-time curve, history curve, and report output. By using the MCGS, complicated hardware and software problems could be avoided and customers can concentrate on the engineering problems themselves. Depending on the needs and features of engineering works, MCGS can configure an industrial monitoring and control system of high performance, high reliability and high specialization.

A. Configuration Software Design

Data object is basic unit for component real-time database. Process to establish online database is to define database. The process to define database include: designate 1) name of variation, 2) type of variation, 3) initial value, 4) numerical range. Variation is as follow in Tab.1:

<table>
<thead>
<tr>
<th>object</th>
<th>type</th>
<th>object</th>
<th>type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection Valve</td>
<td>Switching</td>
<td>Rotate speed</td>
<td>Numeric</td>
</tr>
<tr>
<td>feed valve</td>
<td>Switching</td>
<td>Amplitude</td>
<td>Numeric</td>
</tr>
<tr>
<td>Front Bearing</td>
<td>Numeric</td>
<td>Frequency</td>
<td>Numeric</td>
</tr>
<tr>
<td>Rear Bearing</td>
<td>Numeric</td>
<td>phase</td>
<td>Numeric</td>
</tr>
<tr>
<td>Motor temperature</td>
<td>Numeric</td>
<td>Shift on X axle</td>
<td>Numeric</td>
</tr>
<tr>
<td>pump</td>
<td>Switching</td>
<td>Shift on Y axle</td>
<td>Numeric</td>
</tr>
</tbody>
</table>

Visual Basic Script is as follow in Fig.3. The compile grammar of Visual Basic Script is similarly to Basic can make the configuration process simplify and improve efficiency.

B. Software Function

With the development of computer technology, in many fields, the computer auto-detection and control technology had been introduced. Machine tool spindle in the implementation of the monitoring system measurement, due to the need for synchronous data acquisition and test and analysis,.So it need to adopt computer technology to automatically detect the real time data processing, curve drawing, precision analysis, etc. The introductions of control configuration software technique, the work of front-line operators aren’t obligatory to be very familiar with the knowledge of the spindle and bearing. Through the machine tool lights, the status of equipment can be easy to distinguish whether the good, for the professional and technical personnel, the spindle data collection and analysis of information can be proved by man-machine interface, and then understand the machine spindle at different temperatures, load, speed to run under the state, which is convenient to optimize the design of spindle. Software interface is as follow in Fig.4:

The software gathers data online per-second with network communication and display real-time monitor function on the interface. The system gather data in a synchronous whole-cycle approach way and gather vibration information when start, stop machine or steady-state and process parameters. The system transforms time domain information into frequency domain information with FFT function to get vibration frequency spectrum and analyze spectral component which can provide lots of information for vibration fault diagnosis and manage.

To avoid critical working state of spindle, we need to monitor collision, off load and temperature changing. First, gather information both critical working state and non-critical working state of spindle in measuring technique way and save all of these in a shared database then analyze data with calculation, processing and drafting according the benchmark database. The system can draft and print data list, Shaft Centerline Orbit, Amplitude spectrum, Time-domain waveform, Parameters Stick Figure, Start-stop curve, Bode diagram, Waterfall Plot, tendency chart and axle center location.

Shaft Centerline Orbit: rotor moves eddy motion around a center not only round own center. The eddy motion is called shaft centerline orbits can certain critical rotation speed, space vibration curve and so on. Fig.5 is Shaft Centerline Orbit of System.
Amplitude Spectrum Analysis is a way to break complicated mixed frequency vibration signal into a series of single frequency Shogun Amplitude. Frequency is abscissa, amplitude is longitudinal coordinates in Amplitude Spectrum. We can gain vibration signal and amplitude in frequency with Amplitude Spectrum Analysis. Amplitude Spectrum Analysis is as follow in Fig.6:

![Amplitude Spectrum Analysis of System](image)

**Figure 6. Amplitude Spectrum Analysis of System.**

Time-domain waveform analysis and Spectrum Analysis are often used in machine electric spindle monitor technology; also use shift, velocity and acceleration to express vibration information. Time-domain waveform is the simplest and the most intuitive express form. Waveforms obtain periodic signal, harmonic signal and short-pulse signal. Then we can preliminary judge equipment failure with waveform analyze which can identify resonance phenomenon and modulation phenomenon. Waveform analyze is as follow in Fig.7:

![Time domain waveform of system](image)

**Figure 7. Time domain waveform of system.**

V. ELECTRIC SPINDLE FUNCTION DETECTED

A. Test Equipment

Take a High Speed Electric Spindle testing. Principal axis voltage is 350V, Ampere is 11A, Principal axis power is 6KW, use Steel bearings, maximum rotation speed is 60000rpm. The main experimental apparatus are frequency converter, Thermometer, Vibration Measuring Instrument (with acceleration sensor), Noise Tester, clip-on ammeter, air compressor and cooling equipment, follow in Fig.8.

![Test equipment of electric spindle](image)

**Figure 8. Test equipment of electric spindle.**

B. Test Method

First, fix motorized spindle to V-shape bracket to simulate the normal working state of motorized spindle. Connect the cooling system, the importing and exporting of the cooling water should match to the inlet and outlet on the rear cover. The inlet is in the lower and the outlet is in the upper. Connect the transducer and adjust the parameters. Pure N32 lubricant oil is used to lubricate the system. Start the motorized spindle, run at a low speed without load. Increase the speed step by step (speed step=1000rpm). After running for 20min at a certain speed, the motorized spindle become to be stable, then measure and record the vibratory response, noise, temperature rise of motorized spindle corresponding to every speed. Change the pure N32 oil to 0.5% Cu-containing N32 oil and record the vibratory response, noise, temperature rise of motorized spindle in the same way.

C. Noise Measurement

Electric spindle is in horizontal installation way should not have abnormal screech and impulsive sound when it in rotation speed steady-state with air operation, then measure noise. Lubricate electric spindle with oil, noise sound pressure level should not bigger than 83dB (A). Measurement of sound field environment and installation requirements should be in accord with GB/T 10069.1-1988. Measuring instrument and data processing method should be in accord with GB/T 16769-1997. Noise made by supporting facilities, such as lubricating device, hydraulic device and cooling device, should be treated as background noise. Height of measuring point should in horizontal with centerline of spindle.
Level of noise will markedly elevated with the increase of spindle rotation speed. It increasing relatively gentle when rotation speed is between 10000 to 30000 rpm and tend to increase more obvious when rotation speed is higher than 30000 rpm. Through the comparison of two kinds of lubrication it is clear to see, when use of N32 base oil of 0.5% the nano-copper to lubricate, the noise caused by electrical spindle is less than that of the pure N32 base oil in the same spindle speed. Furthermore on the maximum operating speed (60,000 rpm) of the spindle the resulting noise is lower than that of pure N32 base oil lubrication with 3.1dB.

\[ \delta_{ns} = 1.1895 \times 10^{-5} P_r^{2/3} N_b^{2/3} \cos^{5/3} \theta D_b^{1/3} \]  
\[ K_{rs} = 1.26096 \times 10^3 P_r^{2/3} N_b^{2/3} \sin^{2/3} \theta \cos \theta D_b^{1/3} \]  
\[ \delta_{as} = 4.45 \times 10^{-4} P_a^{2/3} N_b^{2/3} \sin^{-5/3} \theta D_b^{-1/3} \]  
\[ K_{as} = 3.37079 \times 10^3 P_a^{2/3} N_b^{2/3} \sin^{5/3} \theta D_b^{1/3} \]  

The above empirical formula is valid only under the situation in which the ratio of axial load to radial load \( \frac{P_a}{P_r} \) satisfies the full ball contact load, that is:

\[ \frac{P_a}{P_r} \geq 1.2 \tan \theta \]  

This condition is generally satisfied if preload is sufficiently high to prevent any ball being unloaded. To avoid skidding and high wear, bearings should never be partially unloaded during operation. Therefore, an axial preload is usually set to a value high enough to satisfy Eq. (26) even when the bearing is subjected to the maximum radial loads. In addition to preload, another factor that might be considered in determining the radial stiffness of bearings under high speeds is the centrifugal force effect. For angular-contact ball bearings, the radial stiffness may decrease as the speed of the shaft increases when the contact angle is greater than 8.9°. A dimensionless radial stiffness curve as a function of speed and nominal contact angle was published by Harris [18]. From the curve, the radial stiffness of a bearing with a 15° contact angle can be expressed as the following equation related to the rotating speed \( n \) in rpm up to 35,000 rpm, as the following equation related to the rotating speed \( n \) in rpm up to 35,000 rpm:

\[ K_r = K_{rs} (1 - 6.52 \times 10^{-11} n^2) \]  

Where \( K_{rs} \) is the radial stiffness of bearings under a non-rotating situation which can be obtained from Eq.(2). This equation shows that for speeds up to 25,000 rpm, bearing stiffness is softened by only about 4% for 15°angular contact ball bearings.

G. Heat generation of bearing

The major heat generation of the system is caused by the cutting process and the friction between the balls and races of the bearings [19,20]. Assumed that the majority of cutting heat is taken away by coolant and chips, the heat generated by bearings is the dominant cause of temperature change.
The heat generated by a bearing can be computed as:

\[
Q_f = 1.047 \times 10^{-4} M n
\]  

(7)

Where \( Q_f \) is the heat generated power (W), \( n \) is the rotating speed of the bearing (rpm), \( M \) is the total frictional torque of the bearing (Nmm). The total frictional torque \( M \) consists of two parts, one is the torque \( M_1 \) due to applied load and the other one is the torque \( M_2 \) due to viscosity of lubricant. That is:

\[
M = M_1 + M_2
\]  

(8)

\[
M_1 = f_1 P L d_m
\]  

(9)

Where \( f_1 \) is a factor related to the bearing type and load, \( P \) is the bearing preload (N), \( d_m \) is the mean diameter of the bearing (mm).

If \( V_n > 2000 \):

\[
M_2 = 10^{-7} \times f_0 (vn)^{2/3} d_m
\]  

(10)

If \( V_n < 2000 \):

\[
M_2 = 160 \times 10^{-7} \times f_0 d_m^3
\]  

(11)

Where \( f_0 \) is a factor related to bearing type and lubrication method, \( v_0 \) is the kinematic viscosity of the lubricant (mm2/s). From above equations, it is can be seen that the heat generation power is dependent on the viscosity of the base oil of the grease. As the temperature rises, the viscosity will decrease and therefore the heat generation power will decrease, too.

H. Weibull distribution

With the same structure, materials, heat processing and the same processing methods, the life of the bearing is so discrete that under the same conditions the longest life of the bearing is dozens of times of the shortest one; sometimes the difference is even more, so it needs to process the fatigue life data using the mathematical statistic method. Approximately obey the theoretical distribution of the fatigue life of rolling bearings are W. Weibull distribution and the lognormal distribution (that is life value after trypanblau obey the normal distribution), but the W. Weibull distribution is closer to the fatigue life test results, and the data processing is more convenient, so the W. Weibull distribution is used more frequently, it’s distribution function is:

\[
F(L) = 1 - \exp \left[ -\left( \frac{L}{V} \right)^{\beta} \right] \]  

(12)

F(L)-The probability of destruction of the bearing working L hours under certain test conditions. 

b- W. Weibull distribution slop, describing discreteness and stability of the bearing life. 

V-Character life of the W. Weibull distribution, that is the bearing life when the \( F(L)=0.632 \). 

L-The fatigue life in hours. 

In the early time, the data processing method in domestic is mainly based on the JB/T7049-1993 standard, which estimate W. Weibull parameters \( b \) and \( V \) of the bearing life with the methods of the best linear unchanged estimate, the maximum likelihood estimation and the Weibull figure to obtain the test life and the reliability and so on. This method is accurate, and it is suitable for data processing of the complete test, terminated testing experiment, group eliminated test, but this method needs a certain amount of test data, otherwise the real life of the bearing can not be estimated accurately. JB/T7049-1993 is revised to JB/T50013-2000. JB/T50093-1997 recommends a different kind of data processing, which is setting up the parameters, such as the W. Weibull distribution slop assumption, Quality coefficient, inspection level, the acceptable threshold and the refused threshold and so on. In this way, we can simplify the complex data processing, this is more suitable for terminated testing experiment and can reduce the cycle of failure, reduce the test time and save the test cost, but this method has certain limitation and exists certain disparity with other data processing method. With regulation methods of the JB/T50093-1997, such as figure estimation method, the best linear unbiased estimation method, the optimal linear unchanged estimation, the maximum likelihood estimation method and least squares, several sets of test data are processed. After contrast the estimated parameters \( b \) and \( V \) obtained by the six methods above, we find that the result deviation of the least squares method is larger than others, all other methods are almost the same from the angle of result, so when these methods are used in estimating the life of the bearings, the most important one lies in the accuracy and reliability of the collected data [102].

With the contact fatigue life test units, under hybrid bearing conditions, we prove that nano copper additive has the anti-wear properties, and can extend the working life of the bearings. Because the dispersion of the contact fatigue life is so large that the longest life and the shortest one of the same specification specimens is different from each other, therefore, we need many tests to obtain the reliable results from the discrete experimental data. Therefore, 12 samples under every lubricant are tested in complete failure experiments. The test have two groups, the A1-A12 which are the lubricant of no nano copper (abbreviated as N32) and the B1-B12 which are the lubricant of 0.5% nano copper (abbreviated as N32-Cu), the complete failure experiments are under the same loads and speed.

The tested fatigue life values from small to big are listed in table 3-1, the rolling contact fatigue life obey the two parameters weibull function, the expression is as (13):

\[
P(N)s = 1 - e^{-\left( \frac{N}{Vs} \right)^b}
\]  

(13)

The logarithmic form is:

\[
\log \log \left[ \frac{1}{1-P(N)s} \right] = b(\log N - \log Vs) - 0.36222
\]

P(N)s-Under one test stress, the probability when the life of sample is less than N, %. 

Slope parameter \( b \) obeys Weibull distribution, the slope parameter \( b \) obeys Weibull distribution, the slope between the \( \log \log \left[ \frac{1}{1-P(N)s} \right] \) and \( (\log N - \log Vs) \) is:

It represents discrete degree and stability of the contact fatigue life of the samples. Contact fatigue life \( N \) is the stress
circle numbers when the sample is destroyed under the contact circling stress.

Character life Vs obeys Weibull distribution; it is the contact fatigue life when the destroyed probability is 63.2%.

The outcome of two group contact fatigue

Two parameters b and Vs of the Weibull distribution function are processed by the estimate method of the best linear unchanged, the expression is:

\[ b = \frac{1}{2.3026 \sum \frac{C_i(n,r,i) \log N_i}{i}} \]  \hspace{1cm} (14)

\[ \log V_s = \sum \frac{D_i(n,r,i) \log N_i}{i} \]  \hspace{1cm} (15)

Ci and Di are the coefficient of the best linear unchanged method.

The corresponding fatigue life (L10 and L50) of different probability of 0.10 and 0.50 is calculated by the following expressions:

\[ L_{10} = V_s (0.10536)^{\frac{1}{b}} \]  \hspace{1cm} (16)

\[ L_{50} = V_s (0.69315)^{\frac{1}{b}} \]  \hspace{1cm} (17)

Rating life L10 obeys Weibull distribution; it is the contact fatigue life when the destroyed probability is 10%.

Median life L50 obeys Weibull distribution; it is the contact fatigue life when the destroyed probability is 50%.

The estimated parameters are listed in table 4-2, according to the expression (4.3), we can obtain the reliability of the bearings:

\[ R(t) = 1 - P(N_t) = e^{-\left( \frac{N_t}{L_s} \right)^b} \]  \hspace{1cm} (18)

According to the figure estimating principle of the two parameters Weibull distribution, the test data in the table1 are analyzed, the horizontal axis of figure 9 is fatigue time, and the vertical axis is the non-reliability, the fatigue time along the horizontal axis is bigger and bigger from left to right, 12 green triangles represent the data of N32 and the Red Crosses represent the data of the N32-Cu, the line is fitted by these data, from which we can see that the distribute range of the N32 is wider than the N32-Cu, this says that the difference between the life of these bearings is big, in the opposite, N32-Cu is small, under the same non-reliability, such as 10%, the N32-Cu fatigue life is longer than the other one. Making the data in table 2 calculated by expression (6), we find that the rolling contact fatigue life obeys the two parameters Weibull function, as shown in figure 3-12. From the figure 10, we can see that under the same loads and speed, the reliability of the N32-Cu is obviously higher than the N32, it can be concluded that the nano copper additive can extend the fatigue of the bearings.

I. Analysis

The studies of the influence of nano copper as N32 lubricant additives on noise, vibration and temperature rising of the high-speed electric spindle have show, that N32 base lubrication system with 0.5% nano copper particle could reduce noise, rams value of vibration velocity and temperature rising.

It is considered that there are no related home and abroad research or report about the application of nano copper used as lubricant additives of the high-speed electric spindle, therefore, we could regard the tiny bit nano copper which like small balls rolling freely like cobblestone between friction pairs, supporting load, and acting as reducing friction and abrasion.

VI. Conclusion

According to the operational features of machine electric spindle, with the help MCGS configuration software for its real-time monitoring enables real-time data browsing, real-time

<table>
<thead>
<tr>
<th>NO.</th>
<th>slope</th>
<th>Vs (×10^7)</th>
<th>L10 ratio (×10^7)</th>
<th>L50 ratio</th>
<th>ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>N32</td>
<td>1.7059</td>
<td>2.7493</td>
<td>0.7350</td>
<td>2.2178</td>
<td>1</td>
</tr>
<tr>
<td>Cu</td>
<td>2.3851</td>
<td>5.4342</td>
<td>1.7</td>
<td>2.1153</td>
<td>2.88</td>
</tr>
</tbody>
</table>

Figure 9. Weibull distributing probability chart (A: N32, B: N32-Cu)

Figure 10. Test sample reliability-time curve

© 2010 ACADEMY PUBLISHER
and historical data trends showing and other functions, to promptly discover and solve problems and to achieve the desired intent of the experiment. Comparing with the old instrument regulator, the monitoring system has a simple structure, low cost, stable performance, etc. and can be easily to expand through the hardware and software. It has been tested and proven that the test system based on MCGS configuration software able to fully meet the requirements of high-speed machine tool spindle-line monitoring and analysis.

ACKNOWLEDGMENT

The work described in this paper was supported by National Nature Science Foundation of China (Project No.50779056); Eleventh Five-year National Science and Technology Support Program (Project No.2006bbfl01b02).

REFERENCES