Evaluation method of running performance for five-axis machining center based on the "S" specimen

H J Wang¹,², F X Han¹, Y H Gu², B G Rosén²,³ and A N Zou¹,²
¹School of Mechanical and Electrical Engineering, Beijing Information Science and Technology University, China.
²Key Laboratory of Modern Measurement and Control Technology, Ministry of Education, Beijing Information Science and Technology University, China.
³The Rydberg laboratory, Halmstad University, Halmstad, Sweden.

E-mail: wanghongjun@bistu.edu.cn

Abstract. With the development of industries and the advanced manufacturing technology, the performance of the machine tools plays an important role for the product quality. Machining performance of five-axis machining centers, MC, in the manufacturing industry has been a hot research area, where evaluation methods based on cutting of a test piece are common, but it have proved hard to determine the relationship between test piece deviations and machine tool sensor data during manufacturing. An “S” test specimen has the characteristics of open and close angle, variable curvature, thin wall, and low stiffness. The quality of a machined “S” specimen is used to test the characteristics of five-axis MCs. Inaccurate manufacturing results in unqualified parts and the loss of business. Normally geometrical errors are hard to adjust and compensate for in the process. In order to evaluate, and map the relationship between the characteristics of geometrical work-piece deviations from a MC to in-line sensor data, a monitoring system was established in this study. The LABVIEW monitoring evaluation system is developed based on “running performance tracing”. By using a coordinate measuring machine, CMM, and a Scanning Electron Microscope to measure the actual geometry and surface finish of the machined S part and compare it to the ideal geometry, a database and a running performance evaluation model for 5-axis MC based on the “S” specimen was developed. Finally, the effectiveness of the method of evaluation is verified by cutting experiments using a MAZAK five-axis MC. The achievements reported here are helpful for solving the lack of systems to evaluate the running performance of five-axis CNC machine tools for high-end manufacturing industry in China, which has important application prospect and high economic value.

Keywords: Five-axis MC, “S” specimen, evaluation model, running performance, surface finish.

1. Introduction
With complex structure and high precision, five-axis MCs are used for machining complex parts. The running performance of a five-axis machining center (MC) plays an important role on the products’ quality and productivity. The errors of a part are resulted by the comprehensive errors of multi-axis. It is difficult to evaluate the performance of a five-axis MC [1]. The evaluation of machine tools requires a great deal of time and sometimes does not reflect the accuracy of actual cutting. The standard parts for indirect measurement include NAS tester [2] and “S” Specimen. The “S” Specimen has the
characteristics of open and close angle, variable curvature, thin wall, low stiffness, which reflects not only the static errors but also the servo system tracking error, tool positioning error and profile error etc. The geometrical, kinematic characteristics of “S” Specimen have been investigated [3]. The map of stiffness on a surface has been proposed [4]. Zhong Jiang et al. [ref x] introduced an approach based on modeling and simulation of surface morphology [5].

The proposed positioning algorithm is applied to the S-shaped test [6]. The variation of stiffness lead to cutting deformation during an S tester, the vibration and the loss of accuracy have been analyzed [7]. The evaluating accuracy of a five-axis machine tool by measuring the finished tester has been widely studied [8-12]. However, the questions of how to evaluate the effect of processing performance in high speed operation and how to evaluate the performance of machine tools online in real time still remains to be answered.

In this study, a multi-sensor acquisition system for “S” Specimen processing is developed based on the “S” Specimen.

In addition, a mapping model of running performance for Multi-axis CNC Machine Tools based on “S” Specimen is proposed. “S” Specimens are divided into four typical regions, and the corresponding mapping of quality errors, -the surface finish and the dynamic signal characteristics of “S” Specimens is established. The performance evaluation method of the five axis machining centers applied to a MAZAK machining center. The shape and position errors of “S” Specimens were measured by a coordinate measuring machine, and the surface quality of the testers was analyzed by scanning electron microscopy. The validity of the performance evaluation method was proved to be valuable for evaluation of the performance of five-axis MC in real.

2. Geometric characteristics of “S” specimen analysis

“S” specimen in the current test is made from aviation-aluminum alloy (type of alloy). The projection of the upper and lower edge curves of the “S” Specimen on the base is shown in figure 1. S1 is the projection of the top edge on the base surface; S2 is the projection of the bottom edge line on the base plane; C is the intersection point of S1 and S2. Open angle and close angle of the “S” Specimen is shown in figure 2. The outer edge of the “S” Specimen greater than 90° is called “open angle”, less than 90° are called “close angle”. The C point is the turning point between open and close angle.

![Figure 1. The projection of the upper and lower edge curves](image1)

![Figure 2. Machining angle defined](image2)

The curvature of “S” Specimen is shown in figure 3. The A-B curvature is almost linear, then sharply increasing to a bending curvature. After a maximum value, and constant reduction, through the intersection C, the curvature flips make a change direction. The continuity of the surface (shown in figure 4) is mainly G1 and G2 continuous. Because of “S” Specimen complexity structure, open and close angle, non-uniform changes during the machining process, the tool’s spatial violent posture changes, and the cutter axes vector always remains with the S side of the tangent. This enables the machine tool high multi-axis linkage accuracy and performance.
3. Evaluation model based on “S” Specimen precision and surface morphology

3.1. Influence of static performance of machine tool on accuracy of “S” Specimen
The geometric errors of MC include positioning error, straightness error, angular displacement error and squareness error. These errors affect the geometric accuracy of machine tool [13]. These errors will result in the oversized “S” Specimen base and S edge strip, shape and position errors, and sudden surface morphology changes.

3.1.1. Analysis of static accuracy of linear axis
The Kinematic error parameters of three linear axes X, Y and Z are shown in table 1. Taking the X-axis for example, 6 errors generated by the translation along the X axis include 3 linear errors and 3 rotational errors as shown in figure 5. That is, the location error $\delta_x(X)$ along the X-axis, the straightness error $\delta_y(X)$ along the Y-axis, and the straightness error $\delta_z(X)$ in the vertical direction along the Z-axis. In addition, see figure 6, there are three rotation errors $\varepsilon_{xy}$, $\varepsilon_{yx}$, $\varepsilon_{zx}$, and three squareness errors between the X-, Y- and Z-axis.

During machining the base of the S test piece, the rotating axis of the MC are fixed to $A=0$, and $C=0$. The processing methods of hole 1 and hole 2 are fine boring. Hole 1 is the reference hole, error $\delta_{xx}$, $\delta_{yy}$ is determined by measuring the position of the hole 2 relative to the hole 1 as shown in figure 7. By measuring the verticality of the axis of the hole 1 and 2 axis on the upper surface A, the existence of squareness errors $S_{yz}$, $S_{zx}$ is evaluated (see figure 8).

| Description          | Location errors | Straightness error | Angular displacement error |
|----------------------|-----------------|--------------------|---------------------------|
| X-axis motion        | $\delta_x(X)$   | $\delta_y(X)$ $\delta_z(X)$ | $\varepsilon_x(X)$ $\varepsilon_y(X)$ $\varepsilon_z(X)$ |
| Y-axis motion        | $\delta_y(Y)$   | $\delta_y(Y)$ $\delta_z(Y)$ | $\varepsilon_y(Y)$ $\varepsilon_x(Y)$ $\varepsilon_z(Y)$ |
| Z-axis motion        | $\delta_z(X)$   | $\delta_y(X)$ $\delta_z(X)$ | $\varepsilon_z(Z)$ $\varepsilon_y(Z)$ $\varepsilon_z(Z)$ |
| Squareness errors    | $S_{xy}$ $S_{yz}$ $S_{zx}$ | |

Table 1. Kinematic errors of the linear-axes
3.1.2. Analysis of static accuracy of rotating axis

During the processing of the “S” Specimens, it is assumed that the deviation of the actual rotation axis of the C-axis in the X-axis follows the examples shown in figure 9.

When machining the inner contour shown in figure 9a, the actual milling position is offset to the theoretical position clockwise. As a contrast, the actual milling position is offset to a certain value counterclockwise when machining the outer contour corresponding to this point as shown in figure 9b. This error results in the actual thickness of the point greater than the theoretical thickness of the point of the “S” Specimen. The actual distance between the A-A points of the corresponding points is measured (see figure 10a). According to the size of the difference the C-axis rotation axis offset in the X-direction can be determined. Similarly, the corresponding detection points can be set to detect the...
offset in the Y-and Z-directions. Before machining the edge of the “S” specimen, the upper surface is machined with the same tool. If the error exists, the upper surface of the machined surface is inclined. After the “S” specimen is machined, the difference between the two-point B-B’ of the upper surface is measured as shown in figure 10c).

Figure 10. Contour machining (a) Schematic diagram (b) $E_{ac}$ on the geometric error (c) Distribution of measuring points.

3.2. Analysis of dynamic error of machine tool on “S” specimen

Based on the multi-body system error analysis theory, the machining defect model of the machine tool is established. The expression of any point on the “S” surface is solved by using the method of superposition of tool center position and tool direction vector, and then the formula of the corresponding error of each machining point on the surface is derived.

The error position of each machining point can be divided into two branches: “machine tool-tool” branch and ”machine tool-work-piece” branch”. A coordinate system established in each moving body based on the homogeneous coordinate transformation, the tool-center-point and tool direction-vector can be described in the work-piece coordinate system through the motion transformation matrix error, which contains the actual tool path and the actual tool direction.

\[
\{p_r\}_w = [B_w]^{-1} [B_r] \{p_r\}_r
\]

(1)

\[
\{v_r\}_w = [B_w]^{-1} [B_r] \{v_r\}_r
\]

(2)

Where, $\{p_r\}_w, \{p_r\}_r$ respectively represent the coordinates of the position of the cutter head in the work-piece coordinate system and the cutter coordinate system. $[B_w]$ is the actual motion change matrix for the machine tool work-piece,$[B_r]$, i.e. the actual motion change matrix of machine tool cutting. As shown in figure 12, the "machine tool-tool" branch includes 1-5-6-7-8-9, while the "machine tool-work-piece" branch mainly includes 1-2-3-4.
The change matrix is as follows:

\[
[B_w] = [S_1 \ 2]_p [S_1 \ 2]_x [S_1 \ 2]_v [S_1 \ 2]_w [S_1 \ 2]_r [S_2 \ 3]_r [S_2 \ 3]_x [S_2 \ 3]_v [S_2 \ 3]_w [S_2 \ 3]_p [S_3 \ 4]_r [S_3 \ 4]_x [S_3 \ 4]_v [S_3 \ 4]_w [S_3 \ 4]_p \quad (3)
\]

\[
[B_T] = [S_{15}]_p [S_{15}]_x [S_{15}]_v [S_{15}]_w [S_{15}]_r [S_{56}]_r [S_{56}]_x [S_{56}]_v [S_{56}]_w [S_{56}]_p [S_{67}]_r [S_{67}]_x [S_{67}]_v [S_{67}]_w [S_{67}]_p \quad (4)
\]

The relative position relationship between the tool and the work-piece in the work-piece coordinate system is shown in figure 11. The actual position point of the tool center point C from the tool end face D can be expressed as the follows:

\[
[p_c]_w = [p_T]_w + D \times [v_T]_w \quad (5)
\]

From equation (1) (2) (5) can obtain \(x_c, y_c, z_c\). Suppose all the error parameters of \(x_c, y_c, z_c\) are zero. The coordinate of position point can be obtained with ideal condition. The error expression of the three directions is:

\[
E_x = x_c - x_{ct} \quad (6)
\]

\[
E_y = y_c - y_{ct} \quad (7)
\]

\[
E_z = z_c - z_{ct} \quad (8)
\]

The accuracy of “S” specimen is the compiled effects of all machine error. Through detection of the value of error variation between actual and measured values, the performance and accuracy of each moving axis can be evaluated.

3.3. Acquisition of characteristics of machining center based on “S” specimen

In order to obtain the information of MC running performance condition, the vibration, current, noise and temperature signals are used. The vibration of the machine tool will cause the amplitude of the spindle or worktable to exceed the allowable range, resulting in the deterioration of the machined surface of the part. In the machining process, the vibration will produce different degrees of noise, and the spindle current will also change at the same time. Vibration signals are collected by using DASP system (a vibration measuring system developed by Dongfang Vibration Company). A three dimensional piezoelectric acceleration sensor with bolt connection are mounted in the spindle and the work-piece (side of the “S” specimen base). A single direction acceleration sensor with electromagnetic block connection is installed in the A-and C-axis. The current signals of the linear axis and the rotating shaft are processed by a current sensor (CHK50R1). Each sensor is installed on the A-phase power line of each axis-inverter output. In addition, a RS-15A acoustic emission (AE) sensor equipped with 40dB amplifier collects the abnormal sound from spindle or produced by tool wear during machining. The AE sensor is installed on the headstock of the spindle box, shown as figure 12.
The evaluation model of the dynamic performance of the machining center is shown in figure 13. According to the curvature characteristics of the “S” specimen, the switching interval of opening and closing angle and the continuity of the surface, “S” specimen is divided into four regions. An acquisition and analysis system is developed to collect the signals during each milling layer processing based on LabVIEW. The detailed information of each cutting layer is collected, including current, vibration and noise signals. The processed “S” specimens were measured by a coordinate measuring machine and a scanning electron microscope respectively and the “S” specimen measuring data were imported into the database. The deviations of theoretical values and measured values of X-, Y- and Z-values at each point were analyzed. According to the acquisition time, the vibration, the current and the noise data of the corresponding machining section and the performance of the machine tool when machining the corresponding contour was evaluated.

The working flowchart as the follows:

- Obtained “S” specimen post-process instructions;
- Time discretization during the machining;
- While fine machining each layer of the “S” specimen, vibration, current, noise signal data are collected.
- Signal processed and in accordance with the different tester processing time sensitive information and corresponding processing area.
- Compared the standard qualified “S” specimen signals features with the features of the practical “S” specimen;
- Compare the characteristic signals, shapes and thresholds of the normal axes in the machining process are set up, and the surface morphology of the machined parts.
- Evaluation by using the practical information with the standard information.
4. Experimental verification
The evaluation model is used for a vertical five-axis MAZAK MC with a tilting rotary table, shown as figure 14.

4.1. Analysis of three coordinate measurement results of the “S” specimen
The height of S edge strip is 20mm, and the offset value of three measuring lines to the upper surface are 2.5mm, 11.25mm, 16mm each.

The measuring lines are 1#line, 2#line and 3#line, seen as figure 15. The measurement results of the partial points are shown in Table 3, the analysis results could be seen clearly in figure 16-17.

Through the statistical analysis of the data points of three S curves, the vibration deviation of Y-direction was found to be larger, and the distance deviation at 16, 17 point is the biggest. This corresponds to the C-point of the part, the distance deviation of the 7, 8, 9 point is the second largest, and the point corresponds to the B-point of the part surface.
Figure 15. “S” specimen measuring with CMM (a) three measuring lines (b) measurement curve (c) measurement site.

Figure 16. Distance deviation in X-, Y-, and Z- directions along 3# line.

Figure 17. Total distance deviation along 3# line.

Table 2. Geometrical values of surface points of the “S” specimen

|      | Theoretical value (mm) | Actual measured value (mm) | Deviation value (mm) |
|------|------------------------|----------------------------|----------------------|
| X    | Y                      | Z                          | X'                   | Y'                   | Z'                   | ∆X     | ∆Y     | ∆Z     |
| 94.098 | 49.0568               | 17.1305                  | 94.2645             | 49.0473              | 17.1438             | 0.1665  | -0.0095 | 0.0133 |
| 92.6807 | 35.2609              | 17.0129                  | 92.6705             | 35.2638              | 17.007              | -0.0103 | 0.0029  | -0.0059 |
| 91.5905 | 21.4388              | 16.9348                  | 91.5816             | 21.4397              | 16.931              | -0.0089 | 0.001   | -0.0037 |
| 91.6503 | 7.5722               | 16.9551                  | 91.638              | 7.5691               | 16.9513             | -0.0123 | -0.003  | -0.0037 |
| 95.237 | 48.9741               | 8.4553                   | 95.3607             | 48.9677              | 8.4645              | 0.1237  | -0.0064 | 0.0093 |
| 94.173 | 34.8289               | 8.395                    | 94.159              | 34.8344              | 8.3855              | -0.014  | 0.0054  | -0.0095 |
| 93.3683 | 20.6687              | 8.3712                   | 93.3578             | 20.6663              | 8.3644              | -0.0104 | -0.0024 | -0.0068 |
| 93.4246 | 6.4847               | 8.3841                   | 93.4103             | 6.4828               | 8.3772              | -0.0143 | -0.002  | -0.0069 |
| 93.5962 | -7.6986              | 8.415                    | 93.5794             | -7.7004              | 8.4108              | -0.0168 | -0.0018 | -0.0041 |
| 92.1615 | -21.7817             | 8.4486                   | 92.1489             | -21.7681             | 8.4403              | -0.0126 | 0.0135  | -0.0083 |
| 95.8564 | 48.9307              | 3.746                    | 95.9526             | 48.9266              | 3.7566              | 0.0962  | -0.0041 | 0.0106 |
| 94.9838 | 34.5958              | 3.7168                   | 94.9618             | 34.599               | 3.7049              | -0.022  | 0.0032  | -0.0118 |
| 94.3338 | 20.2507              | 3.7222                   | 94.308              | 20.2479              | 3.7139              | -0.0258 | -0.0028 | -0.0083 |
| 94.3874 | 5.89                 | 3.7311                   | 94.36              | 5.8885               | 3.7204              | -0.0274 | -0.0015 | -0.0106 |
| 94.4243 | -8.4701              | 3.7422                   | 94.3965             | -8.4691              | 3.7326              | -0.0277 | 0.0009  | -0.0097 |
4.2. Analysis of the sensor signals during "S" specimen machining

The vibration signals from the part during machined can be obtained as shown in figure 18. Vibration signals from the spindle are shown in figure 19. Analysis of the relationship between signals obtained during the actual processing and the corresponding geometrical measuring point’s data (distance deviations) provide a way of linking the on-line sensor data to expected geometrical deviations.

Sensor signals processed by using db4 wavelet, time domain and frequency domain are listed in table 3.

Figure 18. The vibration signal in X-direction from part (a) Original signal (b) frequency domain.

Figure 19. The vibration signal in X-direction from spindle (a) Original signal (b) frequency domain.

Table 3. Main sensor signals from the monitoring system

| Mean value (g) | margin indicators | kurtosis | Mean frequency (Hz) | Relative energy of first frequency band |
|----------------|-------------------|----------|---------------------|----------------------------------------|
| 0.165287       | 8.224465          | 4.253465 | 630.610274          | 0.333490                               |
| 0.203196       | 4.706014          | 3.436329 | 652.885428          | 0.331180                               |
| 0.203516       | 4.356667          | 3.214722 | 620.288575          | 0.323180                               |
| 0.213184       | 4.296957          | 2.999977 | 677.691592          | 0.337285                               |
| 0.241505       | 4.919377          | 2.919862 | 582.241655          | 0.329824                               |
| 0.292100       | 4.866367          | 2.904250 | 625.132254          | 0.323451                               |

| 0.221508       | 5.384831          | 2.852440 | 557.001919          | 0.323676                               |
| 0.305253       | 5.326490          | 2.982224 | 678.951130          | 0.335667                               |
| 0.374143       | 5.306549          | 2.965261 | 576.347319          | 0.308494                               |
| 0.394331       | 5.052041          | 3.060290 | 670.357880          | 0.342776                               |
| 0.280102       | 5.107896          | 3.013980 | 662.324249          | 0.341480                               |
| 0.264127       | 4.152854          | 2.896036 | 809.493795          | 0.376218                               |
| 0.283333       | 4.600816          | 2.949488 | 760.479086          | 0.365216                               |
| 0.299129       | 5.026934          | 3.051128 | 801.873472          | 0.375502                               |
| 0.262652       | 8.668569          | 3.935178 | 719.692620          | 0.363176                               |
| 0.013957       | 2.739557          | 2.654404 | 417.106758          | 0.252520                               |
The surface finish value of the “S” specimen is obtained by using the SEM. Here, the points on the “S” specimen with especially sensitive to large surface deviations (vibration patterns, waviness) can be identified (see table 4) and linked to predicted geometrical deviations of the final machined part, therefore establishing a normal status pattern of the sensor signals for a geometrically measured and qualified “S”.

If the monitored signals are deviating from the reference signal significantly, a warning signal could be sent to the operator of the MC.

| Table 4. Mapping relationship between the different features |
|------------------------------------------------------------|
| **Point of “S” Specimen** | **Point coordinate data(mm)** | **Signal from monitoring system** | **Surface finish** |
|----------------------------|--------------------------------|---------------------------------|-------------------|
| a                          | -30.2150, 9.3818, 4.7011       | ![Signal from monitoring system](image1.png) | ![Surface finish](image2.png) |
| b                          | 29.4213, 26.3824, 4.5363       | ![Signal from monitoring system](image3.png) | ![Surface finish](image4.png) |
| c                          | 92.6866, -22.6927, 3.7564      | ![Signal from monitoring system](image5.png) | ![Surface finish](image6.png) |

5. Conclusions and Future work

The paper analyzes the advantages and disadvantages of the current five-axis MC inspection and testing parts, the structural characteristics of S-shaped specimen. The S-shaped specimen can reflect the kinematic dynamic performance, machining precision, machining condition and structure rigidity and vibration of the Machine tool. The main conclusions and future issues from this study are:

- A method for evaluating the operation state of 5-axis MC based on S-specimen is proposed.
- A machine tool running condition evaluation system based on S specimen is developed. The data acquisition system can collect dynamic signals included vibration, current, temperature and connect to expected geometrical deviations including surface finish (waviness, chatter, and roughness).
- Furthermore, in the future, there are still a lot to do, such as how to judge the running performance of the 5-axis MC more quickly and with high precision. Additional experiments are required to build a database where sensor data can be robustly connected to geometrical measured deviations, surface finish and control algorithms to minimize the deviations and errors of the produced parts. .
Another future point is to more effectively characterize the surface finish using in-line- or laboratory surface profilers and ISO 4287 and ISO 25178-2 profile- and areal parameters.

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7. References
[1] Qiu J, Wang G M and Gen R P 2013 Roundness errors diagnoses of 5-axis horizontal machining center based on DBB Manufacturing Technology & Machine Tool .08 39-42+46.
[2] Gao X F, Liu Ch Sh, Li Y, Lin J F, Xu J C and Hua Ch Li 2011 Positioning errors detection and identification for A/C axes bi-rotary milling head based in laser interferometer Machinery Design & Manufacture 12 212-14.
[3] S. Weikert 2004 R-test, a new device for accuracy measurements on five axis machine tools CIRP Annals 53(1) 429-32.
[4] NAS979 uniform cutting test. NAS series, metal cutting equipment specifications.1969:34-7
[5] Song Z Y and Cui Y W 2007 S-shape detection test piece and a detection method for detection the precision of the numerical control milling machine CN 101000285A.
[6] Chen D J, Dong L H, Gao X, Wang X F and Fan J W 2016 Error tracing of the complex CNC machine tools based on “S” shaped work piece Journal of Mechanical Engineering 52(11) 155-64.
[7] Wang W,Jiang Zh, Li Q C and Tao W J 2015 A new test part to identify performance of five-axis machine tool-part validation of S part Int. J. Adv. Manuf. Technol .79 739-56
[8] Jiang Zh, Ding J X, Song Zh Y, Du L and Wang W 2016 Modeling and simulation of surface morphology abnormality of “S” test piece machined by five-axis CNC machine tool Int. J. Adv. Manuf. Technol. 85 2745-59.
[9] Qiu J 2014 S form specimen cutting dynamic performance testing and its key technologies China Mechanical Engineering 25(12)1600-04, 1629
[10] Soichi I, Masahiro S, Atsushi M and Tetsuya M 2010 Machining tests to identify kinematic errors on five-axis machine tools Precision Engineering 34 387-98
[11] G H J Florussen, HA M.Spaan and T.M.Spaan-Burke 2016 Assessing the accuracy of five axis machines by comparing machine measurement data with test work piece deviations Procedia Manufacturing 625-32
[12] ISO 10791-7 2014 Test conditions for machining centers, part 7.Accuracy of finished test pieces. ISO (International Organization for Standardization)
[13] ISO 230-7 2006 test code for machine tools, part 7 Geometric accuracy of axes of rotation
[14] Wang H J, Xu X L and Wan P 2014 Rotor System Fault Diagnosis Based on Orbit Manifold Topological Journal of Mechanical Engineering 20(5) 95-101
[15] Wan P, Wang H J and Xu X L 2012 Study of fault diagnosis model based on local tangent space alignment and support vector machine Chinese Journal of Scientific Instrument 33(12) 2789-95