GEOMETRIC ERROR MODELING OF A SUPER-SIZE FLOOR TYPE BORING MACHINE

Bog-Ki Min[1], Hyun-Gwang Cho[1] and Sung-Chong Chung[1]
[1] Hybrid System Design and control LABoratory
School of Mechanical Engineering
Hanyang University
Seoul 133-791, KOREA

INTRODUCTION

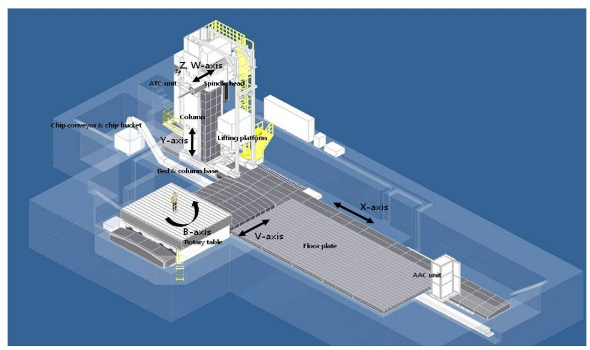
Super-size floor type boring machines are used for heavy-metal milling, boring, drilling and tapping on mega parts for the construction, oil field, wind energy, plant, shipbuilding industries. To make big machining volume, they are made of boring and milling spindle (Z-axis) assembled on the ram (W-axis). Strokes of the X, Y, Z axes are over 10m. As the size is too big, machining error is bigger than small and medium size machine tools. It depends upon deformation of the structures, as well as internal and external heat sources. In general, geometric errors degrade accuracy of machine tools. They are generated from joint errors of moving axes and shape deformations from the machine tool structures. Non-repeatable errors of the joint and shape deformation errors are generated from internal and external thermal error sources. In addition, stiffness variation of the spindle and ram assembly with respect to the joint movement degrades the geometric error.

In this paper, to identify error behavior of the super-size floor type boring machine, homogeneous transformation matrix (HTM) and kinematic error chain [1] are applied for modeling the 3D geometric error including thermal and loading effects. Excitation of internal and external heat sources are to be applied for volumetric thermal behavior analysis. Cutting load as well as weight effect of the spindle and ram is to be analyzed according to the geometric error model as well. In addition, laser tracker is to be applied to confirm volumetric errors of the derived model.

Volumetric Error Model

Fig. 1 shows a super-size floor type boring machine. There are X, Y, Z, V, W and B axes as joint elements. Floor bed, rotary table, column, head, ram, spindle, etc. are shape elements.

Geometric error model is composed of several shape and joint error elements. The shape error is generated from a structure of machine tools It is represented as a shape transformation element in the error model. The joint error is occurred at a moving joint of a machine tool. Rack and pinion for the X-axis, ballscrews in Y, Z, W and V axes, and B-axis are joint elements. Fig. 2 shows the kinematic chain of the machine. CS1 is the origin of the machine. CS2 is the coordinates at the pinion attached to the column. CS1-CS2, CS1-CS4, CS5-CS6, CS7-CS8, CS3-CS9, CS10-CS11, CS12-CS13, CS14-CS15 are shape transformation elements $S_{1\text{-}2}$,$S_{1\text{-}4}$,$S_{5\text{-}6}$, $S_{7\text{-}8}$,



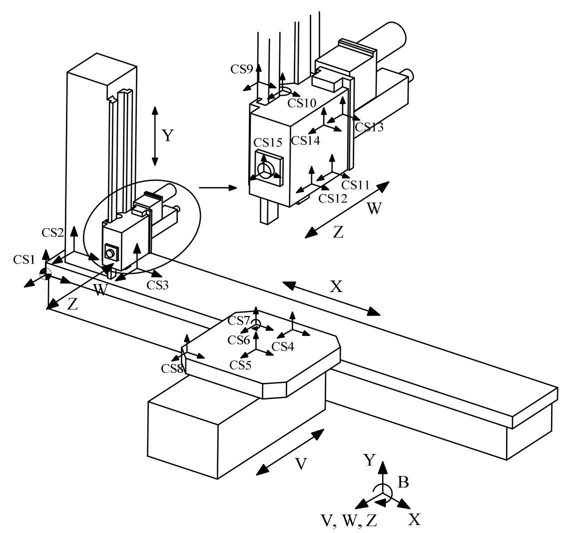


FIGURE 1. SUPER-SIZE FLOOR TYPE BORING MACHINE AND COORDINATE SYSTEMS FOR MODELING.

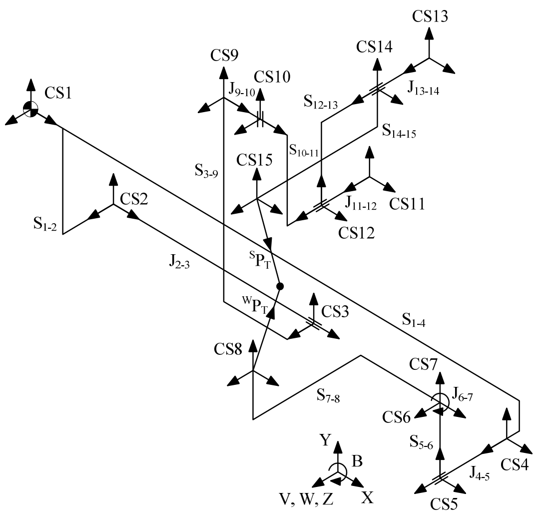


FIGURE 2. KINEMATIC CHAIN OF THE SUPER-SIZE FLOOR TYPE BORING MACHINE.

$S_{3\text{-}9}$, $S_{10\text{-}11}$, $S_{12\text{-}13}$, $S_{14\text{-}15}$, and CS2-CS3, CS4-CS5, CS6-CS7, CS9-CS10, CS11-CS12, CS13-CS14 are joint transformation elements $J_{2\text{-}3}$, $J_{4\text{-}5}$, $J_{6\text{-}7}$, $J_{9\text{-}10}$, $J_{11\text{-}12}$, $J_{13\text{-}14}$, respectively.

Ahn [2] and Kim [3] modeled volumetric errors in a three-axis machine tool by homogeneous transformation matrices considering geometric and thermal deformation errors. Contrary to the small machine tools, the super-sized floor type boring machine has bigger height. Temperature difference between the floor and ceiling generates significant thermal deformation of the column. In addition cutting load and self-weight of the ram and spindle induce deformation. To model these effects, shape transformation elements and joint transformation elements are to be generalized as follows:

$$[S_{1-2}]_{actual}=\begin{bmatrix} 1 & -\varepsilon^s_{z1}(T) & \varepsilon^s_{y1}(T) & a_1+\Delta a_1(T) \\ \varepsilon^s_{z1}(T) & 1 & -\varepsilon^s_{x1}(T) & b_1+\Delta b_1(T) \\ -\varepsilon^s_{y1}(T) & \varepsilon^s_{x1}(T) & 1 & c_1+\Delta c_1(T) \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad [S_{1-4}]_{actual}=\begin{bmatrix} 1 & -\varepsilon^s_{z2}(T) & \varepsilon^s_{y2}(T) & a_2+\Delta a_2(T) \\ \varepsilon^s_{z2}(T) & 1 & -\varepsilon^s_{x2}(T) & b_2+\Delta b_2(T) \\ -\varepsilon^s_{y2}(T) & \varepsilon^s_{x2}(T) & 1 & c_2+\Delta c_2(T) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$[S_{3-9}]_{actual}=\begin{bmatrix} 1 & -\varepsilon^s_{z3}(T) & \varepsilon^s_{y3}(T) & a_3+\Delta a_3(T) \\ \varepsilon^s_{z3}(T) & 1 & -\varepsilon^s_{x3}(T) & b_3+\Delta b_3(T) \\ -\varepsilon^s_{y3}(T) & \varepsilon^s_{x3}(T) & 1 & c_3+\Delta c_3(T) \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad [S_{5-6}]_{actual}=\begin{bmatrix} 1 & -\varepsilon^s_{z4}(T) & \varepsilon^s_{y4}(T) & \Delta a_4(T) \\ \varepsilon^s_{z4}(T) & 1 & -\varepsilon^s_{x4}(T) & b_4+\Delta b_4(T) \\ -\varepsilon^s_{y4}(T) & \varepsilon^s_{x4}(T) & 1 & \Delta c_4(T) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$[S_{5-6}]_{actual}=\begin{bmatrix} 1 & -\varepsilon^s_{z4}(T) & \varepsilon^s_{y4}(T) & \Delta a_4(T) \\ \varepsilon^s_{z4}(T) & 1 & -\varepsilon^s_{x4}(T) & b_4+\Delta b_4(T) \\ -\varepsilon^s_{y4}(T) & \varepsilon^s_{x4}(T) & 1 & \Delta c_4(T) \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad [S_{7-8}]_{actual}=\begin{bmatrix} 1 & -\varepsilon^s_{z5}(T) & \varepsilon^s_{y5}(T) & a_5+\Delta a_5(T) \\ \varepsilon^s_{z5}(T) & 1 & -\varepsilon^s_{x5}(T) & b_5+\Delta b_5(T) \\ -\varepsilon^s_{y5}(T) & \varepsilon^s_{x5}(T) & 1 & c_5+\Delta c_5(T) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$[S_{10-11}]_{actual}=\begin{bmatrix} 1 & -\varepsilon^s_{z6}(T) & \varepsilon^s_{y6}(T) & a_6+\Delta a_6(T) \\ \varepsilon^s_{z6}(T) & 1 & -\varepsilon^s_{x6}(T) & b_6+\Delta b_6(T) \\ -\varepsilon^s_{y6}(T) & \varepsilon^s_{x6}(T) & 1 & c_6+\Delta c_6(T) \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad [S_{12-13}]_{actual}=\begin{bmatrix} 1 & -\varepsilon^s_{z7}(T) & \varepsilon^s_{y7}(T) & \Delta a_7(T) \\ \varepsilon^s_{z7}(T) & 1 & -\varepsilon^s_{x7}(T) & b_7+\Delta b_7(T) \\ -\varepsilon^s_{y7}(T) & \varepsilon^s_{x7}(T) & 1 & c_7+\Delta c_7(T) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$[S_{12-13}]_{actual}=\begin{bmatrix} 1 & -\varepsilon^s_{z7}(T) & \varepsilon^s_{y7}(T) & \Delta a_7(T) \\ \varepsilon^s_{z7}(T) & 1 & -\varepsilon^s_{x7}(T) & b_7+\Delta b_7(T) \\ -\varepsilon^s_{y7}(T) & \varepsilon^s_{x7}(T) & 1 & c_7+\Delta c_7(T) \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad [S_{14-15}]_{actual}=\begin{bmatrix} 1 & -\varepsilon^s_{z8}(T) & \varepsilon^s_{y8}(T) & \Delta a_8(T) \\ \varepsilon^s_{z8}(T) & 1 & -\varepsilon^s_{x8}(T) & b_8+\Delta b_8(T) \\ -\varepsilon^s_{y8}(T) & \varepsilon^s_{x8}(T) & 1 & c_8+\Delta c_8(T) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$[J_{2-3}]_{actual}=\begin{bmatrix} 1 & -\varepsilon_{z1}(x,T) & \varepsilon_{y1}(x,T) & x+\delta_x(x,T)+P_x(T)\cdot x \\ \varepsilon_{z1}(x,T) & 1 & -\varepsilon_{x1}(x,T) & \delta_y(x,T) \\ -\varepsilon_{y1}(x,T) & \varepsilon_{x1}(x,T) & 1 & \delta_z(x,T) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$[J_{4-5}]_{actual}=\begin{bmatrix} 1 & -\varepsilon_{z2}(v,T) & \varepsilon_{y2}(v,T) & \delta_x(v,T)-S_{vx}\cdot v \\ \varepsilon_{z2}(v,T) & 1 & -\varepsilon_{x2}(v,T) & \delta_y(v,T) \\ -\varepsilon_{y2}(v,T) & \varepsilon_{x2}(v,T) & 1 & v+\delta_z(v,T)+P_z(T)\cdot v \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$[J_{6-7}]_{actual}=\begin{bmatrix} 1 & -\varepsilon_{z3}(r,T) & \varepsilon_{y3}(r,T) & \delta_x(r,T) \\ \varepsilon_{z3}(r,T) & 1 & -\varepsilon_{x3}(r,T) & \delta_y(r,T) \\ -\varepsilon_{y3}(r,T) & \varepsilon_{x3}(r,T) & 1 & \delta_z(r,T) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$[J_{9-10}]_{actual}=\begin{bmatrix} 1 & -\varepsilon_{z4}(y,T) & \varepsilon_{y4}(y,T) & \delta_x(y,T)-S_{xy}\cdot y \\ \varepsilon_{z4}(y,T) & 1 & -\varepsilon_{x4}(y,T) & y+\delta_y(y,T)+P_y(T)\cdot y \\ -\varepsilon_{y4}(y,T) & \varepsilon_{x4}(y,T) & 1 & \delta_z(y,T)+S_{yv}\cdot y \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$[J_{11-12}]_{actual}=\begin{bmatrix} 1 & -\varepsilon_{z5}(w,T) & \varepsilon_{y5}(w,T) & \delta_x(w,T) \\ \varepsilon_{z5}(w,T) & 1 & -\varepsilon_{x5}(w,T) & \delta_y(w,T)+S_{wy}\cdot w \\ -\varepsilon_{y5}(w,T) & \varepsilon_{x5}(w,T) & 1 & w+\delta_z(w,T)+P_z(T)\cdot w \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$[J_{13-14}]_{actual}=\begin{bmatrix} 1 & -\varepsilon_{z6}(z,T) & \varepsilon_{y6}(z,T) & \delta_x(z,T) \\ \varepsilon_{z6}(z,T) & 1 & -\varepsilon_{x6}(z,T) & \delta_y(z,T)+S_{zy}\cdot z \\ -\varepsilon_{y6}(z,T) & \varepsilon_{x6}(z,T) & 1 & z+\delta_z(z,T)+P_z(T)\cdot z \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (1)$$

Where, ε^s_{xi}, ε^s_{yi}, ε^s_{zi} (i =1~8) and ε_{xi}, ε_{yi}, ε_{zi} (i =1~6) are rotational errors of shape and joint transformation elements. Δa_i, Δb_i and Δc_i (i =1~8) are translational errors of each shape transformation elements by thermal deformation and load. S_{xy}, S_{vx}, S_{yv}, S_{wy} and S_{zy} are squareness errors by thermal deformation and load. P_x, P_y and P_z are linear thermal expansion of feed axes. δ_x, δ_y and δ_z are positioning and straightness errors of feed axes.

REFERENCES

[1] Slocum A H. Precision machine design. Englewood Cliffs, N.J. Prentice Hall: 1992.

[2] Ahn J Y, Chung S C. Identification and Compensatory control of time-varying Volumetric Errors in Machining Centers. Proceedings of the ASPE 1999 Annual Meeting. 1999: 248-235.

[3] Kim K D, Chung S C. On-Machine Inspection System Accuracy: Improvement using an Artifact. Journal of Manufacturing Systems. 2004; 4: 299-308.