Design of Precision Roll Lathe with a Weight Capacity of 3 Tons

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1 Introduction

Owing to increasing demands for large-scale micro-structured optical films in the field of flat panel display industry, much attention is being given to roll-to-roll forming process as an economical mass production tool. Precision roll lathe is a high precision machine tool which is used to produce optical quality surfaces or complex microstructures on the large roll mold by use of single point diamond cutting tools.

In view point of film-forming process, continuous direct forming process, shown in Figure 1, is being an alternative tool over normal continuous forming process that uses UV curing resin [1]. In this process, the micro patterns on a roll mold are directly transferred to the thermoplastic substrate or film without the help of UV curing resin. To enhance the replication ratio, continuous direct forming process requires high pressure and temperature, so the weight of the roll mold normally increases up to 3 tons.

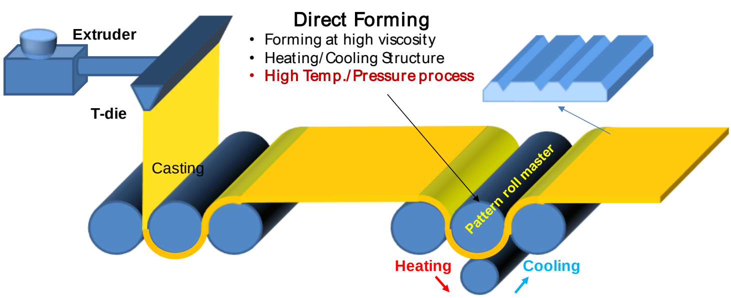


Figure 1: Concept of continuous direct forming process

In this study, we present the design of precision roll lathe which is able to machine heavy rolls up to 3 tons. Also, the method to enhance the load capacity of hydrostatic spindle is discussed.

2 Design of Roll Lathe

Figure 2 shows structural layout of designed precision roll lathe. Maximum roll size is about ϕ600 x 3,000 mm (pattern length up to 2,500 mm). This machine consists of three linear axes (Z & X & W) and two rotary axes (C & B). In all axes including tail stock, hydrostatic oil bearings are adopted to implement high precision, stiffness and damping. In Z-axis, double linear motors are used to minimize a heat generation from motors during rapid transverse machining process. To minimize a structural distortion caused by heavy roll, machine is designed as symmetric as possible. Machine base is made of granite and is supported by four air isolators at the corners to suppress floor vibrations.

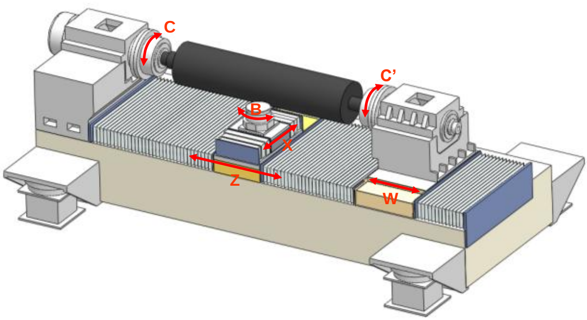
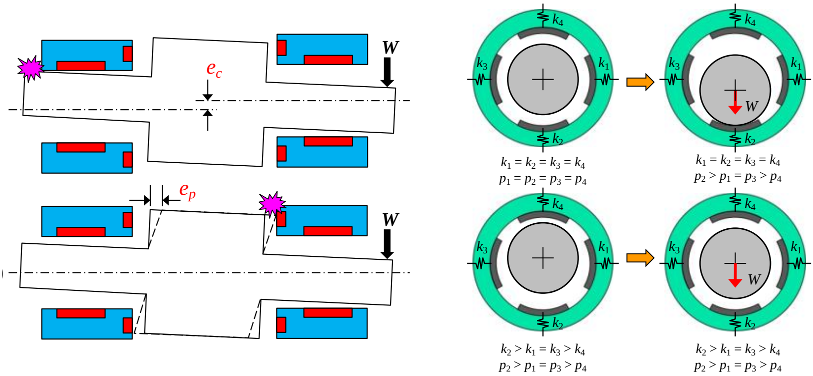


Figure 2: Layout of designed roll lathe

In the design of roll lathe, load capacity of the hydrostatic spindle is one of the most important design issues since heavy rolls up to 3 tons should be supported. Considering the additional load such as chuck, load capacity of the front journal bearing is basically designed to be about 2 tons at the eccentricity of ε=0.4.

3 Improvement of load capacity

Even though the load capacity of the hydrostatic spindle is theoretically enough, there are inevitable error sources that limit the load capacity. If there is concentricity or perpendicularity error in the spindle assembly, as shown in Figure 3(a), load capacity of the spindle can be significantly reduced by partial contact. One way to overcome this problem is to increase the load capacity of the hydrostatic bearing in order that same load is supported at relatively lower eccentricity. But, it requires bigger size spindle or higher oil supply pressure, which makes design difficult.

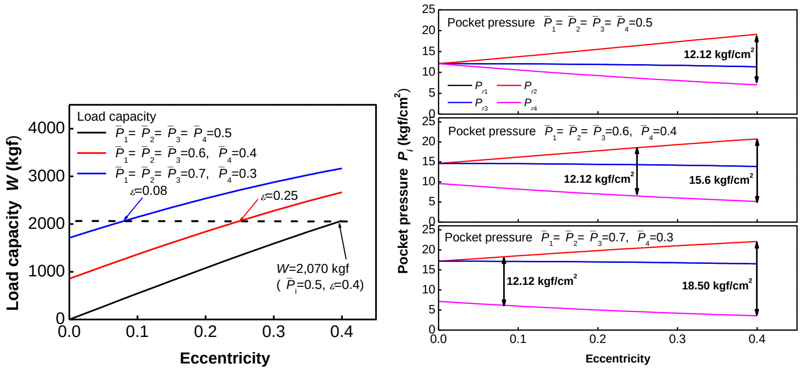


(a) Error sources in spindle assembly (b) Concept of increasing load capacity

Figure 3: Improvement of load capacity

To increase the load capacity without increasing the spindle dimension or the supply pressure, simple method shown in Figure 3(b) can be applied. In normal design (upper case in Figure 3(b)), capillary coefficient of each hydrostatic pad is set to be same, so the pocket pressure of each pad is same at no load condition. If a load is applied, spindle shaft moves downward. In this case, pocket pressure of the bottom pad increases, while that of the top pad decreases. This pressure difference determines the load capacity. If the capillary coefficient of bottom pad is increased and that of top pad is reduced, then pocket pressure difference is generated at ε=0. It means that the center of spindle shaft moves upward at no load condition and more clearance margin at the bottom pad is secured.

Figure 4(a) shows simulation results. $\overline{P}_i$ $(i = 1,...,4)$ is the ratio between pocket pressure and oil supply pressure at ε=0. If the capillary coefficient of each pad is set so that $\overline{P}_i$ is 0.5, the load capacity at ε=0.4 is 2,070 kgf. If the capillary is changed so that $\overline{P}_2$ is 0.6 and $\overline{P}_4$ is 0.4, then load capacity at ε=0.4 is increased to 2,667 kgf. If the capillary is changed more so that $\overline{P}_2$ is 0.7 and $\overline{P}_4$ is 0.3, the load capacity at ε=0.4 is increased to 3,168 kgf. It clearly shows that the load capacity can be enhanced about 50% by simple capillary change. Figure 4(b) shows pocket pressure of each pad according to eccentricity at different capillary setting. In case of $\overline{P}_2 = 0.7$ and $\overline{P}_4 = 0.3$, pressure difference is increased to 18.5 kgf/cm^2, which is about 50 % increase compared with that of normal design.



(a) Load capacity (b) Pocket pressure

Figure 4: Simulation of load capacity and pocket pressure at different capillary setting

4 Conclusion

In this study, precision roll lathe, which is able to machine heavy rolls up to 3 tons, is designed. To achieve high precision and stiffness, hydrostatic oil bearings are adopted in all axes. Also, the machine is designed as symmetric as possible to minimize structural distortion. To improve the load capacity of the hydrostatic spindle within limited size, simple method that changes capillary coefficient is worked out and it is proved by simulation that load capacity can be enhanced about 50%.

References:

[1] J.S. Oh, C. H. Park, J. Y. Shim, "Preliminary Evaluation of Hydrostatic Spindle for Precision Roll Lathe with Heavy Load," Proceedings of KSPE Autumn Conference, pp. 523-524, 2011