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Research on Estimation of Clamping Force Decrease Due to Workpiece Rigidity Reduction in Machining

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***Abstract*—Clamping force reduction during machining operation is a serious problem to achieve accurate machining with side clamping. Conventional estimation method for the clamping force reduction is only applicable to the faced pair fixturing such as machine vise fixturing. In this study, we propose an estimation method for the reduction in clamping force applicable to general-purpose side clamping tools. An FEM-based estimation procedure for clamping force reduction is proposed. The proposed method is evaluated by comparing estimated results. From the comparison, the proposed method which can be applicable to general fixturing situations shows equivalent performance to the conventional method.**

Keywords—workholding, machining, side clamp, clamping force reduction

I. INTRODUCTION

In small-lot production, finish machining of near net shape parts is an important process. Recent development of near net shape part fabrication such as additive manufacturing increase the shape complexity and decrease the fixturing area. As the results, utilizing side clamping methods such as machine vises and side clamps are commonly used. One of the causes of precision deterioration in such machining is the deformation of the workpiece due to clamping forces[1]. Therefore, the management of clamping forces becomes an important issue. Regarding the clamping force, it has been reported that clamping forces decrease during machining as the rigidity of the workpiece declines. In previous studies, it is possible to evaluate the clamping force reduction in a machine vise fixturing[2]. However, the method cannot apply to the multi-point fixturing. This is because the conventional method of clamping force reduction assumes a one-dimensional arrangement of fixtures and workpieces. Therefore, it is necessary to develop a general estimation method which is applicable to multi-point fixturing.

In this study, we propose a method for estimating the reduction in clamping force which can be applicable to workpiece clamping situations using general-purpose side clamps. In this report, a FEM-based estimation procedure is proposed, and evaluate the method by comparing the estimation results for vise fixturing.

II. METHOD FOR ESTIMATING THE REDUCTION IN CLAMPING FORCE

In the context of vise clamping, a mechanical model using a one-dimensional spring arrangement approximation has been proposed to evaluate the effect of changes in workpiece rigidity on clamping force. The validity of the method has been verified by comparing the results of machining experiments. The results show that, with appropriate evaluation of both workpiece and machine vise rigidity, accurate predictions can be made for a various machining workpiece. As a specific model for the reduction in clamping force, the machine vise clamping the workpiece is modeled as a series of connected elastic springs sandwiched between rigid bodies, as shown in Fig. 1. It is assumed that the displacement between the rigid bodies occur in the initial clamping state and it remains unchanged during machining operation. Under this assumption, the relationship between the reduced clamping force F' and the initial clamping force F is formulated as shown in equation (1).

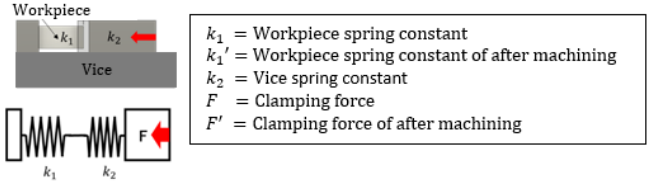

Fig. 1 Modeling of vise holding

$$F' = \frac{\alpha(k_2+k_1)}{k_2+\alpha k_1}F \qquad (1)$$

where k_1 represents the initial spring constant of the workpiece, k_1' represents the spring constant of the workpiece after machining, and k_2 represents the spring constant of the vise. The ratio $\alpha = \frac{k1'}{k1}$ indicates the relative change in the spring constant of the workpiece. According to this equation, the clamping force after reduction can be determined based on k_1, k_1' and k_2. In actual cutting processes, displacements of the machine vise and the workpiece are small enough compared to their dimensions. Therefore, the workpiece stiffness can be approximated as a linear spring constant.

III. ESTIMATION METHOD FOR CLAMPING FORCE REDUCTION APPLICABLE TO SPATIAL ARRANGEMENTS

To estimate the clamping force reduction in cases where fixtures are arranged in a two-dimensional manner, the assumptions used for the machine vise are extended. Specifically, it is assumed that the position of the fixture mounting surface when the clamping force is initially applied does not change during machining. By introducing this assumption, the following estimation procedure based on elastic analysis using FEM can be derived.

1. Define an elastic body (equivalent fixture) that has the same spring constant k to the clamping fixture..

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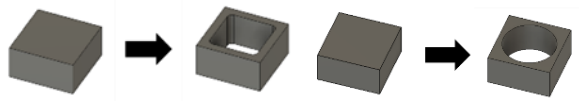
2. Clamp the workpiece in its pre-machining shape using the equivalent fixture as the FEM model. Then, apply a load equivalent to the initial clamping force *F* to the elastic body.
3. Calculate the displacement δ of the equivalent fixture using FEM-based elastic deformation analysis that takes solid contact into account.
4. As the machined situation, clamp the workpiece in its post-machining shape with the equivalent fixture and input the displacement δ obtained in step 3 as a displacement constraint.
5. Perform another FEM-based elastic deformation analysis, considering solid contact, to calculate the reaction force at the constrained point, which will give the clamping force after reduction *F'*.

This procedure does not contain any assumption of fixtures and workpiece arrangement. In this study, commercial finite element software was used for the analysis. To evaluate the validity of the proposed method, a comparison of estimation results was conducted by applying the proposed method to the vise clamping problem.

IV. TARGET FOR EVALUATION

The machining case examined for evaluating the reduction in clamping force is illustrated in Fig. 2. The workpiece material used is A2017. First, as shown in Fig. 2(a), we considered the machining of a square hole from a block shape for two cases: an inner wall thickness of 3 mm and 4 mm. For the circular hole machining, the pre-machining shape remains the same block shape, but the machining shape is changed to a circular hole. The dimensions of the hollow section were analyzed for three diameters: D = 35.4 mm, 33.4 mm, and 31.4 mm. In the pocket machining case, as shown in Fig. 2(c), we assumed a more complex shape for both the outer and machined profiles compared to square and circular hole machining. The thickness of the side walls was set to two options: 3 mm and 5 mm.



(a)Square hole (b)Round hole

(c)Pocket

Fig. 2 Evaluation cases

V. EVALUATION RESULTS

The results of actual machining experiments were compared with the calculated results obtained from equation (1) and the analysis results using the proposed method. To evaluate the applicability of the analysis method utilizing the simulated elastic body. Fig. 3 to 5 illustrate the comparison of clamping force reductions for square hole machining, round hole machining, and pocket machining. The differences between the conventional method and the proposed method were found to be relatively good, with square hole machining showing errors of -2.3% to -4.3%, circular hole machining -0.85% to 2.2%, and pocket shape machining -4.2% to -4.9%. These results indicate that the proposed method has the potential to achieve estimations comparable to those of the conventional method.

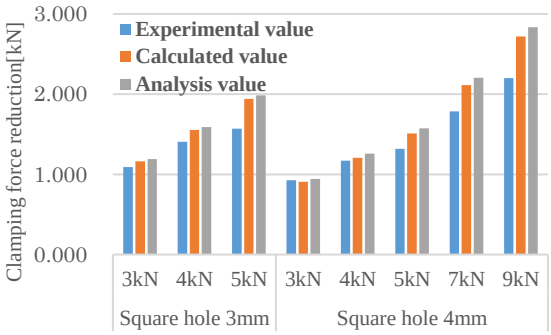


Fig. 3 Comparison of clamping force reductions for Square hole

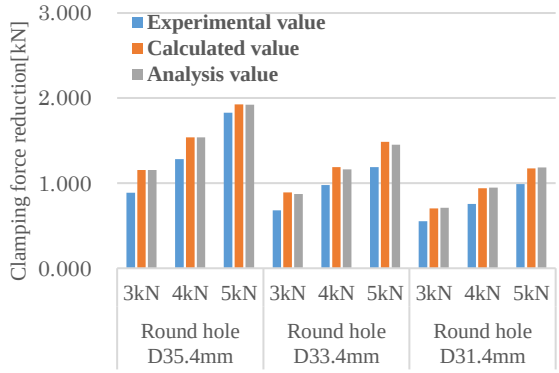


Fig. 4 Comparison of clamping force reductions for Round hole

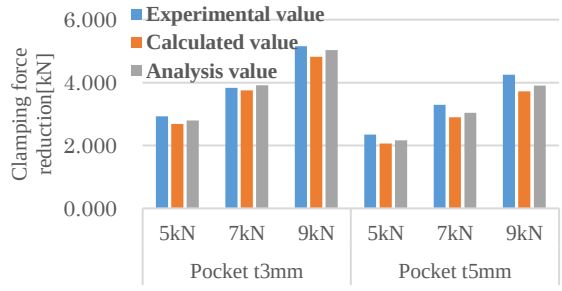


Fig. 5 Comparison of clamping force reductions for Pocket

VI. CONCLUSION

In this study, we proposed an estimation method for clamping force reduction which is applicable to multi-point clamping. The feasibility of the proposed method is compared to the conventional method at the vise fixturing. From the comparison, the proposed method shows equivalent performance to the conventional method in machine vise fixturing situations.

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