THE INFLUENCE OF THE MEASURING DEVICE ON THE MILLING PROCESS STABILITY

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ABSTRACT

The paper presents the influence of the force measuring device on the stability of the surface milling process. Taking into account the limit value of the cutting depth, for a stable milling operation, it is indicated the fact that the critical parameter that influences the process stability is represented by the dynamic radial rigidity of the milling tool. Based on the results obtained, it can be observed that the stability of the tool - measuring device – holder system is not affected in case of long overhang distances, but is reduced in case of measuring devices mounted on short holders.

1. INTRODUCTION

The rigidity of the force measuring device has an important influence on the stability and precision of the milling machines [4].

A parameter that can be modified is the rigidity of the dynamometer measurement section.

Of equal importance is the geometric dimension of the assembly formed of the sustaining spindle, measuring device and milling tool.

2. THE EFFECT OF THE MEASURING DEVICE ON THE PROCESS STABILITY

A dynamometer which is designed for use on a machine tool must not significantly interfere with the machining performance or process. This requirement is particularly true for the stability of the machine tool.

It has been shown that the limit depth of cut for stable milling $b_{lim,min}$ can be approximated by:

$$b_{lim,min} \approx \frac{-1}{2n_T K_s [Re(G_{or})]_{min}}$$

(1)

where:

$[Re(G_{or})]_{min}$ – minimum value of real component of oriented frequency response function

K_s – cutting stiffness (material and tool dependant)

n_T – average number of teeth engaged in cutting

If the radial dynamics are equal in all directions and the modes are separated in frequency then the minimum value of the oriented frequency response function can be approximated by:

$$[Re(G_{or})]_{min} \approx \frac{-\mu}{4(k\zeta)_{min}}$$

(2)

where:

μ – orientation factor

$(k\zeta)_{min}$ – minimum radial dynamic stiffness of all vibration modes

Substituting (2) into (1) yields:

$$b_{lim,min} \approx \frac{2(k\zeta)_{min}}{\mu n_T K_s} \qquad (3)$$

This shows that the critical machine parameter which limits stability is the minimum radial dynamic stiffness at the tool.

There are two design requirements regarding dynamic stiffness for a milling torque dynamometer introduced between the tool holder and the tool.

    I.   Minimize the geometric effect of adding the dynamometer on the dynamic stiffness at the tool.

    II.   Minimize the added flexibility inherent in the dynamometer as reflected on the tool.

The first requirement is explained with reference to Figure 1 where it is shown that the dynamometer width h adds to the overhang distance d of the tool from the spindle bearings. The stiffness of spindle modes is very sensitive to the distance d even if the dynamometer itself is an absolutely rigid element. Spindle modes are vibrational modes where the tool essentially behaves as a rigid extension of the spindle. The tool stiffness decreases significantly with increases in the tool overhang distance d for spindle modes. Therefore, it is essential to keep the dynamometer width h as small as possible so that the overhang distance d is not significantly larger than the machining process requires.
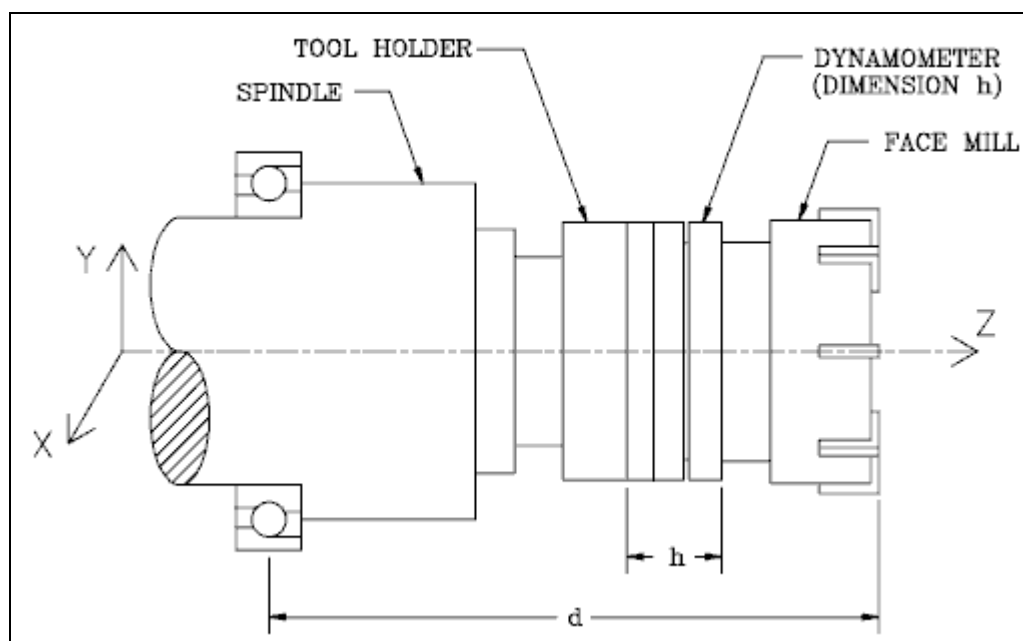

Fig. 1 – Effect of the dynamometer on tool overhang distance

The second requirement is related to the fact that dynamometer is not a perfectly rigid element. In reality the dynamometer must have some intentional flexibility in the sensing element. This flexibility is added to the flexibility of the spindle and tooling system to reduce the tool stiffness. Therefore, the dynamometer should be rigid enough not to significantly reduce the tool stiffness.

The effects of the dynamometer on the dynamic stiffness discussed above pertain to the bending deflections in the transverse X and Y axis directions. These effects are under normal circumstances more important than the analogous effects on torsional deflections around the Z axis. The milling torque dynamometer is a torsional sensor, but its design must still respect the bending design requirements I and II so that the machine tool stability will not be significantly compromised.

The effect on stability of adding the dynamometer to the machine tool can be determined from a finite element model of the spindle structure in bending. The bending finite element model uses the same element choices as the torsional finite element model with different formulations of the element mass and stiffness matrices.

The five lowest frequency modes for the spindle, holder, dynamometer and tool system in bending are presented in Figure 2. The natural frequency and stiffness at the tool is indicated with each mode. A comparison of mode stiffnesses with the dynamometer installed and two configurations without the dynamometer is presented in Table 1. In one case the dynamometer is removed and the same holder (65 mm extension length) is used. In the other, a longer extension holder (100 mm extension length) is used without the dynamometer which places the tool at approximately the same distance from the spindle bearings as the configuration with the dynamometer installed.
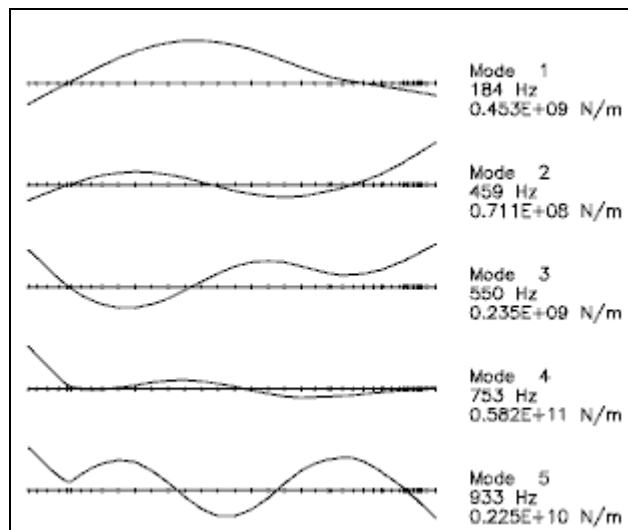

*Fig. 2 - Bending finite element modes - mode shapes, natural frequencies (Hz)
and radial stiffnesses (N/m)*

Mode No.	Dynamometer Installed 65 mm Holder	Dynamometer Removed 65 mm Holder	Dynamometer Removed 100 mm Holder
1	4.85×10^8	6.75×10^8	4.39×10^8
2	6.98×10^7	2.05×10^8	5.95×10^7
3	2.35×10^8	1.12×10^8	3.24×10^8
4	5.74×10^{10}	7.15×10^{10}	6.0×10^{10}
5	2.25×10^9	2.43×10^9	2.44×10^9

Table 1. Radial bending stiffness comparison (N/m)

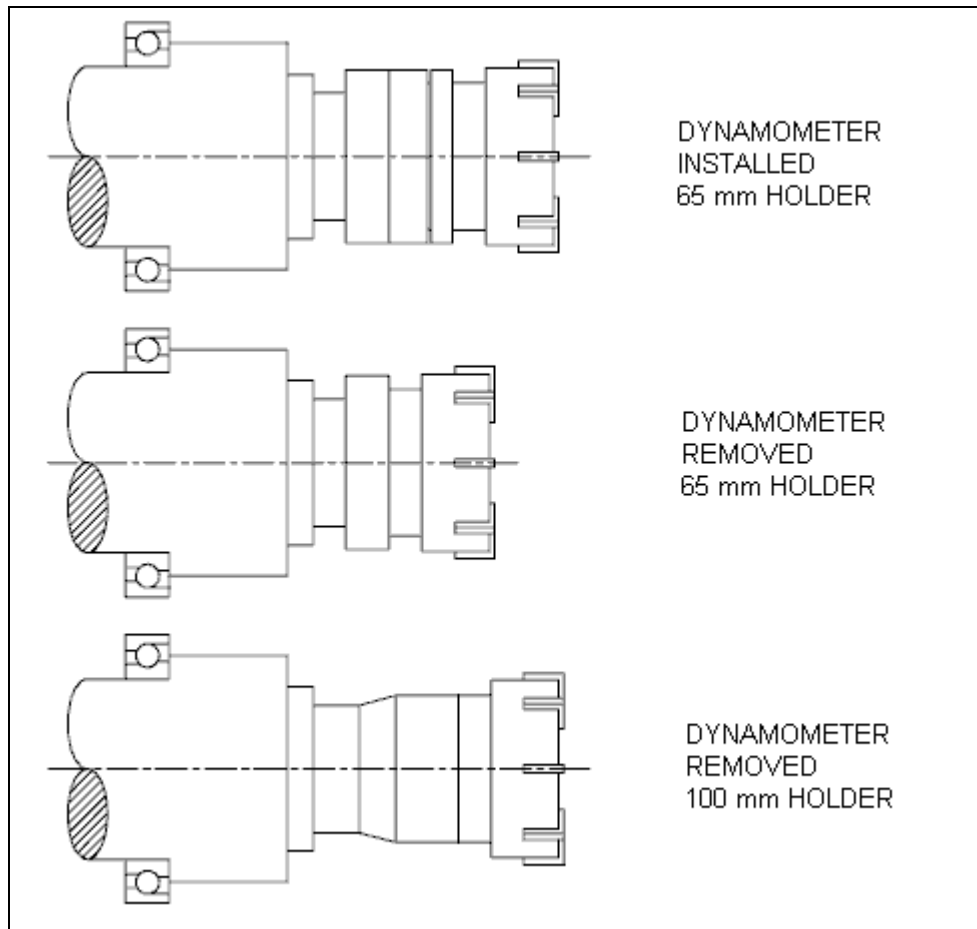The three configurations compared in Table 1 are shown in Figure 3.

Fig. 3 – Configurations of dynamometer and tool holders compared in Table 1.

3. CONCLUSIONS

In Table 1, the lowest stiffness value for each configuration is underlined. If the damping ratios of all limiting modes are assumed equal, these results show that the dynamometer does not affect stability for equal tool overhang distances but does reduce stability if the required overhang distance is less than can be obtained with the dynamometer installed on the shortest holder. This problem might be corrected by building the dynamometer directly into the tool holder or perhaps the tool and eliminating the separate dynamometer component which increases the tool overhang distance.

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