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Finite element analysis of the dynamically created portal in the huge machine tool of "travelling column" type

Stanislau Dounar[1], Alexandre Iakimovitch[2], Andrzej Jakubowski[3*]

[1] https://orcid.org/0000-0002-6201-8340
[2] https://orcid.org/0000-0002-1138-1350
[3] https://orcid.org/0000-0002-0331-3147

[1,2] Belarusian National Technical University, Mechanical Engineering Faculty
Nezalezhnasci 65, 220127 Minsk, Belarus
[3] Maritime University of Szczecin, Faculty of Marine Engineering
Waly Chrobrego 1-2, 70-500 Szczecin, Poland
e-mail: a.jakubowski@am.szczecin.pl
✉ corresponding author

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Abstract

In this paper, a special configuration for the huge multipurpose machine tool of "travelling column" type was investigated by the finite element analysis. Internal degrees of freedom of a bulky system consisting of the ram, stock, column, sledge and bed, were implemented by the hydrostatic guides. A simulation of coupling two assembled columns into the portal structure was completed. The results of this work showed that temporal joining raises the spindle static rigidity by 1.39–1.91 times depending on the direction (mostly longitudinal – along the X-axis). The simulation also revealed the robustness of a whole-machine resonance pattern (11.7–39.0 Hz) to "column–to–portal coupling". Eight types of eigenmodes were analyzed for frequency intervals from 0 to 80 Hz. A decrease by 2.9 times of the resonance peaks of a frequency response function was observed in the case of a portal structure creation. In case of columns-to-portal transition, stable cutting just at resonance frequencies (resonance overriding) becomes allowable. Overall, the "Portal" structure is recommended for intermittent cutting machining by raised high spindle unit at frequencies below 40 Hz.

Introduction

Multipurpose machine tools of the "travelling column" type are consigned to milling, drilling and boring large and tall workpieces. The workpiece is usually unmovable when machined. The column which is assembled with a stock, a ram, and a spindle unit carrying the tool, moves. The tool has three degrees of freedom besides its own rotation. The machine tool is bulky, precise, and high-priced; as a result, it works for many years and is renovated rather than replaced.

This work is related to a renovation project focusing on a group of unified "travelling column" machine tools of one branch. The large structural parts – columns and bed sections – were preserved with the refinishing of the hydrostatic guides. Naturally aged parts from cast iron are expected to be nearly free from residual stress, thus dimensionally stable which is a valuable feature for the precise machine tool. The stocks, rams, and spindle units were newly designed and produced. *Computerized numerical control* (CNC) system was provided for machine tool. Reconfiguration of the structural parts (columns, sledges, bed sections) was also provided during renovation. Furthermore, a new “travelling column” configuration is presented in this work and its capabilities from the view of the rigidity of the configuration are investigated by *finite element analysis* (FEA) simulation (Zienkiewicz & Taylor, 2000).

Machine tool configuration and the aim of the work

This work is devoted to a software comparison between two configurations (structures) of the “travelling column” machine tool (Herrero & Bueno, 2001; Munoa et al., 2013) – the “Monocolumn” (Figure 1a) and the “Portal” (Figure 1b). The last configuration is temporary, just “on-demand emerging” one. It may be noted as *situate portal* and else *dynamically created portal* (DCP). DCP or briefly “Portal” is built by two coupled monocolumns moving close together. Other times, every column may move alone, according to its own CNC program.

A column with the ram Rm1 (assembled) is depicted in Figure 1a. This column touches its paired, symmetrical column, ram Rm2, in Figure 1b. Ram Rm1 is advanced at 1.6 m and the parallel ram Rm2 is nearly fully retracted.

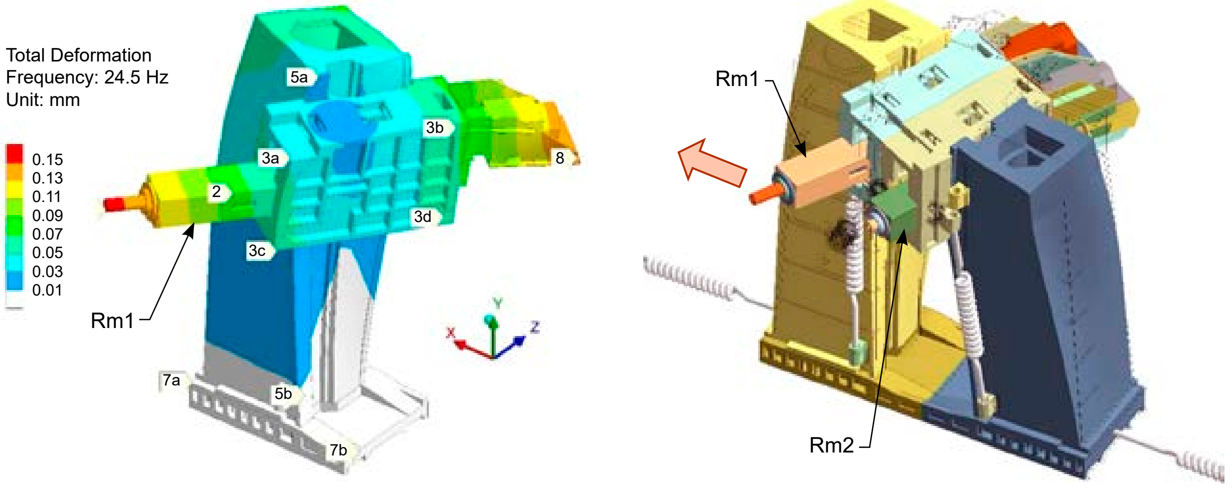
A monocolumn assembly (Figure 1a) provides cutting using the double telescopic spindle unit (at the left end of ram Rm1). The precise boring spindle (Figure 1b), may advance axially (along Z) up to 2.6 m. This range is provided partly by the ram (0.59×0.59 m) axial advance. The Ram side surface 2 is slipping into the hydrostatic guides inside stock 3. Corner areas of stock 3 are marked 3a, 3b, 3c, 3d. The stock causes a vertical degree of freedom (along Y) due to hydrostatic guides (5a–5b) on column 5. The stock has a moving range of 4.25 m, and the column is of 6.7 m in height. The column is fixed to sledge 7, slipping longitudinally along X by hydrostatic guides 7a–7b on the underlying bed (not shown); the spindles are driven by motor 8.

The main problem of the monocolumn is a low dynamic rigidity at the spindle in the direction X. It is caused mainly by torsional resonance M3. The axis of torsion is vertical (parallel to Y) and it migrates inside triangle 3a–3b–5a. Even a small angle of torsion turns into big linear displacements at the ends of “1b–8” line (leverage effect).

The spindle flexibility is particularly high in the top stock position marked as “raised high spindle” (RHS – Figure 2, right). The adverse stock position near the bottom of the column is named the “low down spindle” (LDS – Figure 2, left). The spindle moving up from LDS to RHS causes vibration problems and cutting process instability. This limits precision and output if the tall workpiece is machined.

As seen in Figure 1, a stock is placed on the right from the column (right design). The renovated machine group possesses columns as of right design so of the left one. The modern tendency is to mount two or more travelling columns upon a bed, and to machine several workpieces in a parallel way.

During the renovation, it was proposed to install two monocolumns – L and R (Figure 2) – upon the bed with common guides; columns may provide machining independently under different CNC channels supervising. Two diverse workpieces, W1 and W2 (Figure 2), undergo separate boring and milling by tools T1 and T2. The stock at the right column R, is in the RHS position with the advanced ram.



a) b)

Figure 1. Torsional resonance M3 of “Travelling column” machine tools for configurations: “Monocolumn” (a; 24.5 Hz) and “Portal” (b; 24.04 Hz). Arrow – exciting harmonic force F_x^d

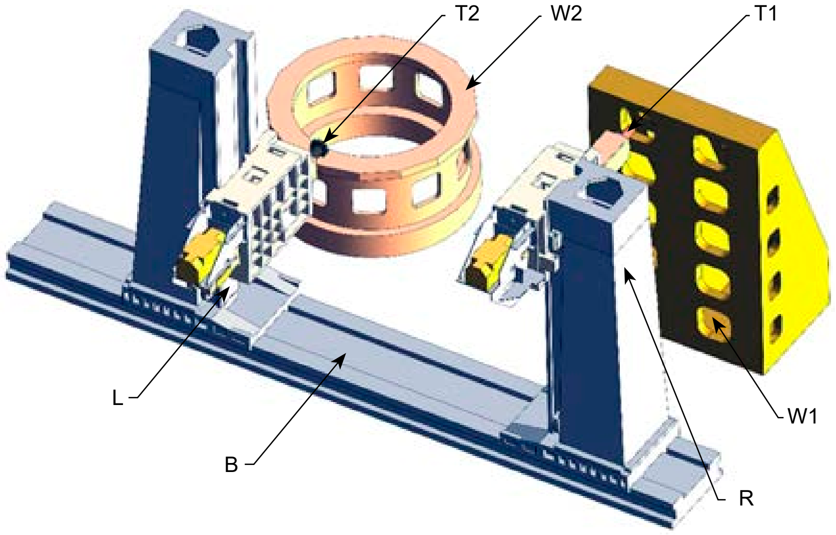
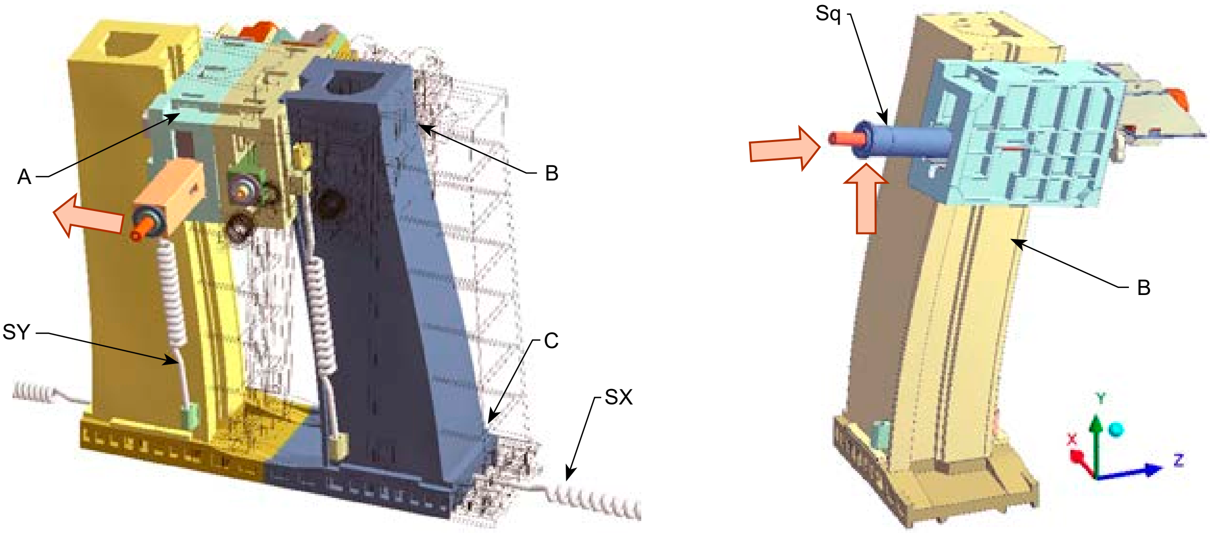


Figure 2. Parallel machining of workpieces W1, W2 by tools T1, T2, placed at the left and right monocolumns L, R (B – common bed). L relates to the low-down spindle (LDS) and R – to raised high spindle (RHS)



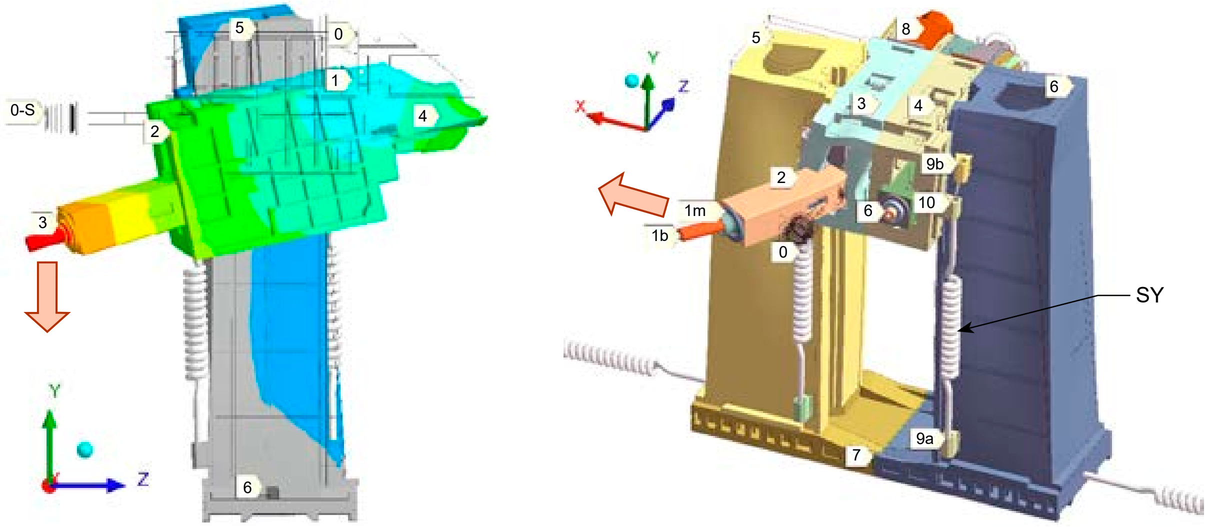
a) b)

Figure 3. Structures “Portal” and “Monocolumn”, rocking at low frequencies during bending resonances excitement: a) eigenmode M1 (12.48 Hz); b) eigenmode M2 (12.72 Hz). Arrows – harmonic forces F_x^d, F_y^d, F_z^d, able to excite corresponding modes. Sq – spindle unit quill

The stock at the left column is moved down 3 m to the LDS position with the ram retracted; such a position brings sufficient spindle rigidity.

The machine tool with two independent columns on common guides is well known (Munoa et al., 2013). The feature of the presented configuration is that one column has a right-side design (R) and second column has a left-sided (L) one. The columns with stocks mirror each other; both stocks are facing each other. This configuration is convenient to provide collision-free, two-ram machining of the large workpiece. However, the main benefit of the mirroring columns lies in a critical case of raised high spindle (RHS) machining. Monocolumns of the left and right design may be joined in the new load-bearing system – “Portal” (Figures 1b, 3a and 4b). Columns are to touch each other by stock sides and lock up rigidity contour. The double structure (“Portal”) provides additional static and dynamic rigidity when RHS cutting is provided, demonstrating the need for FEA simulation as is the goal of the work presented.

The “Monocolumn” and “Portal” structures are depicted in Figure 3 and Figure 4. The arrows relate to cutting force components, applied from the workpiece to spindles while the springs simulate feed drives.



a)

b)

Figure. 4. "Monocolumn" (a – M4; 23.51 Hz; spindle force F_y) and "Portal" (b – M7; 70.82 Hz; spindle force F_x) exited according to eigenmodes

The marker systems on Figure 1 and Figure 4b are the same. Stocks 3, 4 are brought together by the CNC and are clamped to each other on corners 3a–3d (Figure 1). This is because preliminary FEA simulation has revealed the necessity to bond stocks without any slipping possibility. Otherwise, the effect of portal creation would be negligible. Monolithic system of stocks 3, 4 (Figure 4b) are named "stock-pack". Both columns and "stock-pack" create portal 5–3–4–6. Vertical opening between columns has a width of 2 m and a height of 7.1 m (counting from top to guides X). The portal rests on two sledges, contacting along line 7. The whole structure is driven in the X direction by the SX springs pair. Each spring behaves as a backlash-free, rack-pinion drive.

There are two parallel vertical drives (ball screws) for every stock – on the spindle side and on the motor side of column too. Every screw is simulated by a pair of SY springs. They abut on 9a, 9b column bracket and interact with nut 10 on the stock.

All hydrostatic guides are considered fully free from sliding with no friction and resonance according to eigenmode M1 may be freely excited by a horizontal force F_x^d (arrow on Figure 3a). The following movements for portal during M1 excitation include:

- each column bending (marks B, C),
- sledges reciprocating along X-guides (mark C),
- stock-pack oscillating vertically relatively to columns Y-guides (mark A).

It is clear that column bending is the main participant in spindle X-amplitude while sledge X-oscillation is on a second position and far away.

The DCP is represented as a no monolithic contour which causes inner slipping borders on the hydrostatic guides. The hydrostatic guides may be clamped and fixed, however, it leads to small inaccuracies caused by oil layer closing–opening. Therefore, all guides are assumed to be fulfilled with an ideal liquid.

It is assumed (in this paper) that after the portal structure creation, only one ram is used to machine at the same time (e.g., 2 on Figure 4b) and tt is driven by a spring SZ (hidden inside the stock). Ram 2 carrying the spindle unit consists of the milling spindle 1m and boring spindle 1b (going through milling one). Both spindles are designed for intermittent cutting, when cutting force may oscillate.

FEA-model and machine tool parameters

An FEA-model is built for static, modal, and harmonic analysis of "Monocolumn" and "Portal" structures. The experience (Vasilevich et al., 2015; Vasilevich et al., 2016) gained during the simulation of heavy "travelling column" machine tools, is used. Every cast iron structural part of the machine tool was presented by a separate finite element mesh. These meshes were joined together by a special surface finite element mesh set (contact pairs). Mostly contact pairs were assigned "bonded" status (no movements on contact surfaces) and hydrostatic guides were simulated as contact pairs with "no separation" status meaning free sliding without the possibility open contact or interference for neighboring bodies. Note that both stocks in the stock-pack interact only at corner areas (3a, 3b, 3c and

3d on Figure 1a), where contact pairs are tuned to “bonded” status.

The spindle unit bearings were secured against rotation and the damping ratio was taken as $\xi = 4\%$ during the harmonic simulation. Every spring SX has a rigidity of 600 N/μm, and each spring SZ has a rigidity of 400 N/μm. Every stock is supported in the vertical direction by a spring SY system with a total rigidity of 400 N/μm. The spindle unit radial rigidity is tuned in the FEA model as equal to 950 N/μm at the milling spindle (ϕ332 mm) end and 120 N/μm at the boring spindle (ϕ200 mm) end. The latter value relates to a boring spindle pushing forward 500 mm from the milling one. The spindle unit rigidity is much higher than the spindle rigidity of monocolumn $J^{st,d}_{\text{mono}}$ or portal $J^{st,d}_{\text{port}}$. The latter considers the flexibility of a whole load-bearing system of the machine tool.

Static comparison of “Column” and “Portal” structures

This paper focuses on the static rigidity of the spindle for monocolumn (J^{st}_{mono}) and of that for portal (J^{st}_{port}) as well as the same dynamic parameters J^{d}_{mono} and J^{d}_{port}. The spindle rigidity is almost the same as the tool rigidity for the investigated kind of machine tools. Rigidity is important both for machining precision and for cutting process stability (falling to auto-oscillations). The main threat is “regenerative chatter” (Jafarzadeh & Movahhedy, 2017; Lu et al., 2018). It is a currently accepted necessity (Olvera et al., 2012; Lopez de Lacalle & Lamikiz, 2008) to provide rigidity above the threshold $[J^{\text{thres}}_{x,y,z}] = 20$ N/μm in any direction. This applies to both static and dynamic rigidity at the end of the tool-bearing spindle. An excess of the threshold $[J^{\text{thres}}_{x,y,z}]$ guarantees cutting process stability. If spindle rigidity were lower ~10 N/μm, auto-oscillations become very likely.

A static testing force, $F^{st}_{x,y,z}$, of 1 kN was applied to the milling spindle end along coordinates X, Y, Z when the machine tool was in the RHS position. The value of the force is not the issue for FEA-model linearity and simulated spindle displacements allows for calculation of rigidity (Table 1). It is sufficient because is higher than the threshold level $[J^{\text{thres}}_{x,y,z}]$ at 20 N/μm for both the monocolumn and the portal structures.

The monocolumn spindle is the most flexible in the X direction (rigidity threshold is exceeded by three times only). This is due to a stock-ram torsional movement about axis Y. In static mode, the portal is a more rigid structure than the monocolumn with a maximal difference (1.91 times) in the longitudinal direction X. In other directions, the portal is one and half times stiffer than the monocolumn.

Table 1. Spindle static rigidity for configurations “Monocolumn” and “Portal” along coordinate axes

Milling spindle rigidity by axes, N/μm	Monocolumn (J^{st}_{mono})	Portal (J^{st}_{port})	Rigidities ratio $J^{st}_{\text{port}}/J^{st}_{\text{mono}}$
X	61.6	118.3	191%
Y	90.4	135.5	149%
Z	123.7	173.0	139%

The monocolumn has different rigidities in the X, Y, Z directions (e.g., rigidity along Z in double exceeds one along X (Table 1)). The portal demonstrates a more stable behavior when the cutting force vector rotates. Directional rigidities differ no more, than 1.46 times; this is a positive trait of the portal.

Modal analysis and important resonances

Modal analysis disclosed a similarity of eigenmodes patterns for “Monocolumn” and “Portal” configurations. As eigenmode frequencies, so eigenmode shapes are near the same (Table 2).

The main (first, lowest) resonance M1, and the second one M2 proved to be “one-fourth wave” column oscillations in the X and Z directions respectively (Figure 3). Eigenmode M1 includes sledge reciprocation along with the X guides. However, column bending is the dominant movement here.

Eigenmode M3 is described above. Mode M4 excitement leads to (Figure 4a) stock oscillations (0 to 1 transition – named *Y-oscillation*), but mainly to ram-stock pecking. Pecking consists of alternate rotary motion of the stock. Line 1–2 loses horizontal orientation, ram axis 3–4 becomes declined, and the spindle unit 3 displaces considerably from the initial position 0-S due to the “leverage effect”.

Pecking is the main pattern for mode M5 and is presented in mode M6 as well. Stock pecking eigenmodes (M4–M6) harms diameter precision of the machining. These modes should be damped or omitted (Portentoso et al., 2017; Stepan et al., 2017). Ram pecking is caused by the stock and Y-guides collective skewing.

Eigenmodes M5–M6 have a complex movement template. Besides stock pecking, they include ram axial oscillation (*Z-oscillation*) and column *XY-swinging* (column top goes to the left when sledge goes to the right along X-guides). Eigenmodes M5–M6 are split. For example, modes M6a and M6b have only different phase angles between Z-oscillations and column XY-swinging.

Table 2. Frequency and shape of eigenmodes

No.	Eigenmode	Frequency, Hz		Pattern of oscillation movement (1, 2, 3 – order of influence)
		Monocolumn	Portal	
1	M1	11.70	12.48	Rocking along X (along with bed guides)
2	M2	12.72	13.34	Rocking across X (across bed guides)
3	M3	24.29	24.04	Torsion about Y
4	M4	23.51	26.85	Y-oscillation of stock-pack (1) plus stock-pack pecking (2)
5	M5a	30.78	30.44	Stock-pack pecking (1) plus Z-oscillation of rams (2)
6	M5b	–	31.63	Z-oscillation of rams (1) plus stock-pack pecking (2)
7	M6a	38.68	38.29	Z-oscillation of rams (1), XY-plane column swinging (2), stock-pack pecking (3)
8	M6b	38.72	39.02	Z-oscillation of rams (1), XY-plane column swinging (2), stock-pack pecking (3)
9	M7	74.10	70.82	Ram bending in XZ-plane in phase to motor swinging
10	M8	77.98	73.52	Ram bending in XZ-plane in antiphase to motor swinging

Eigenmodes M1–M6 excitation embrace all machine tools so that the modes should be called *whole-machine* ones. Modes M1–M6 pertain to low-frequency interval and M5–M6 to middle-frequency one. Modes M7–M8 relate to local and high-frequency resonances. Here (Figure 4b), only ram bending is observed. The ram console (1.6 m long) resonates similar to the "one-fourth wave" scheme and the massive motor partially counterbalances ram bending. The spindle unit and the motor move in-phase for M7 mode and in an antiphase manner at the frequency of M8 mode.

Harmonic analysis

Excitation was provided by harmonic force with 1 kN amplitude, directed one by one along X, Y, Z. Force was applied at the boring and milling spindle ends (arrows on Figures 1, 3, 4). This is the *frequency response function* (FRF) entry parameter for every figure. Displacement amplitude, in the place of force application, serves as the FRF's exit parameter. The FEA tests were provided with the frequency step of 1 Hz in the interval 0–100 Hz for a damping ratio of 4%, uniformly distributed across structural parts.

The spindle unit did not reveal its own dynamics at such relatively low frequencies. The first resonance of the spindle unit – "spindle bends in bearings" – was observed at 211.8 Hz. At all FRFs shown below, special attention should be paid to resonance peaks higher than 50 µm. It means that dynamic rigidity decreases below threshold 20 N/µm.

A pair of milling spindle FRFs are represented in Figure 5 for the case of longitudinal (X) excitation.

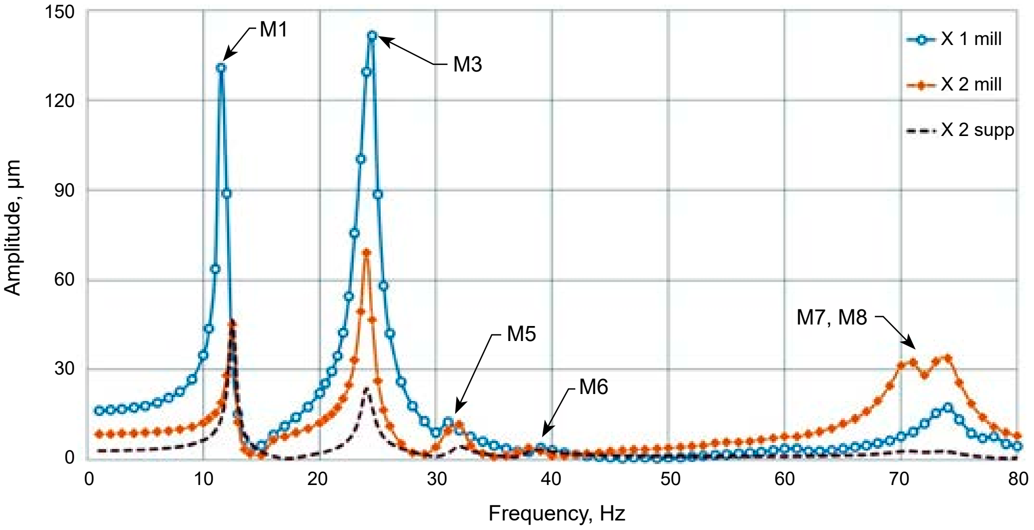


Figure 5. Milling spindle longitudinal FRF (spindle force F_x^d along X – spindle face displacement along X) for monocolumn (X 1 mill) and portal (X 2 mill)

Curve “X 1 mill” relates to the monocolumn structure and curve “X 2 mill” relates to the portal one. Curve “X 2 supp” presents a supporting face (at stock) amplitude. The leverage effect of long ram is absent here. So, curve “X 2 supp” describes column movements and is the lowest on the picture.

The FRF in Figure 5 demonstrates whole-machine resonance peaks (M1–M6). On the left from M1, pre-resonance (static) interval is placed (≤ 10 Hz). On the right from the weak peak M6, post-resonance interval is stretched. It is interrupted by local-character resonances M7–M8. The range from ~35 to ~65 Hz seems to be very calm and appropriate for intermittent cutting.

The main conclusion from the FRF in Figure 5 is that a monocolumn-to-portal transition effectively reduces resonance peaks, thus only for whole-machine resonances. The spindle amplitude is lowered by 2.9 times for bending eigenmode M1 and by 2.04 times for torsional mode M3.

Critically high amplitudes (≥ 50 μm) are observed for portal configuration only inside a narrow frequency slot (23.5–24.5 Hz) if mode M3 is excited. Other resonance frequencies permit intermittent cutting (a form of dynamic excitation). The possibility to machine near resonance will be named below *resonance overriding* (RovR).

Figure 6 presents the monocolumn and the portal FRFs in the Y direction (force F_y^d at the milling spindle end – displacement Y amplitude in the same position). Undoubtedly, the portal is a much more rigid structure in the low-frequency resonances vicinity. The peak of the strong M2 mode is 2.27 times lower for the portal than for the monocolumn.

The portal effectively counteracts to stock-pack pecking M4 (dynamic rigidity higher by 2.78 times) signifying that resonance M4 was dangerous for the monocolumn in case of vertical excitation. Here stock skewing is significantly amplified by the leverage effect at the long, advanced ram.

The level of modes M5, M6 excitation is similar for both configurations of the “travelling column”. This is because of the local scale of ram axial oscillations along Z. Such resonance may be reduced by a *tuned-mass damper* (TMD) or more complicated solutions (Munoa et al., 2013).

Generally, the DCP is a positive design solution to withstand resonance excitation in the vertical direction. Machining with RovR is permissible for all whole-machine resonances.

Harmonic force F_z^d was applied in Z direction to the end of the boring spindle. A related pair of FRFs (Figure 7) pointed out to strong excitation in mode M2. Bending oscillations of a monocolumn are inappropriately high with the amplitude reaching 88 μm and the rigidity going down to 11.3 N/μm. The monocolumn-to-portal coupling increases rigidity by 1.69 times just to the threshold $[J_z^{\text{thres}}] = 20$ N/μm. The portal creation matches with other measures of auto-oscillation prevention (Muhammad et al., 2017).

The portal influences the dynamic rigidity near M4–M6 in an alternative manner. Column-to-portal coupling enhances rocking about M4–M5. On the other hand, it damps oscillation near the M6 peak. The monocolumn FRF in Figure 7 (“Z 1 bore”) demonstrates peak M1 i.e., bending resonance in the X direction. Such resonance may be excited by

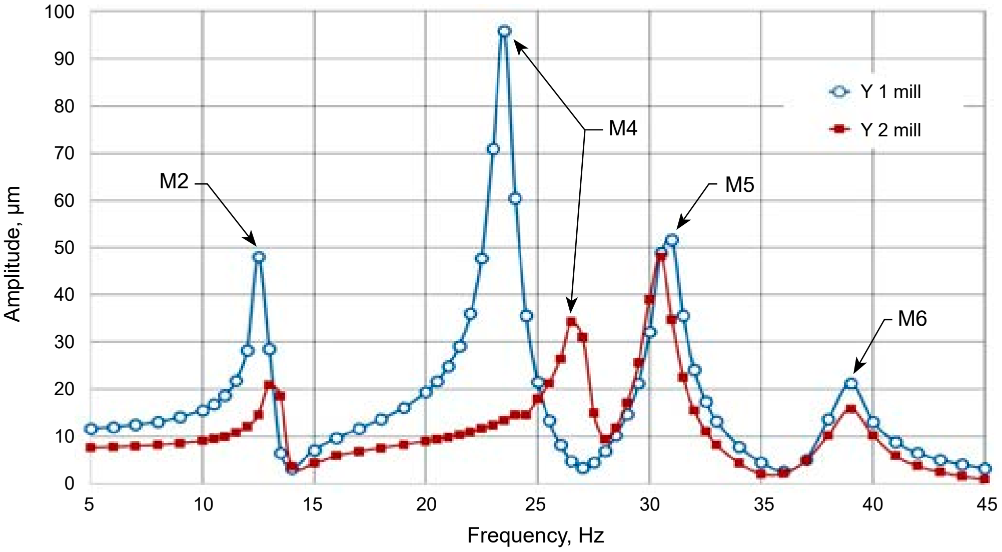


Figure 6. Vertical milling spindle FRF (spindle force F_y^d along Y – spindle displacement along Y) for structures: “Monocolumn” (Y 1 mill) and “Portal” (Y 1 mill)

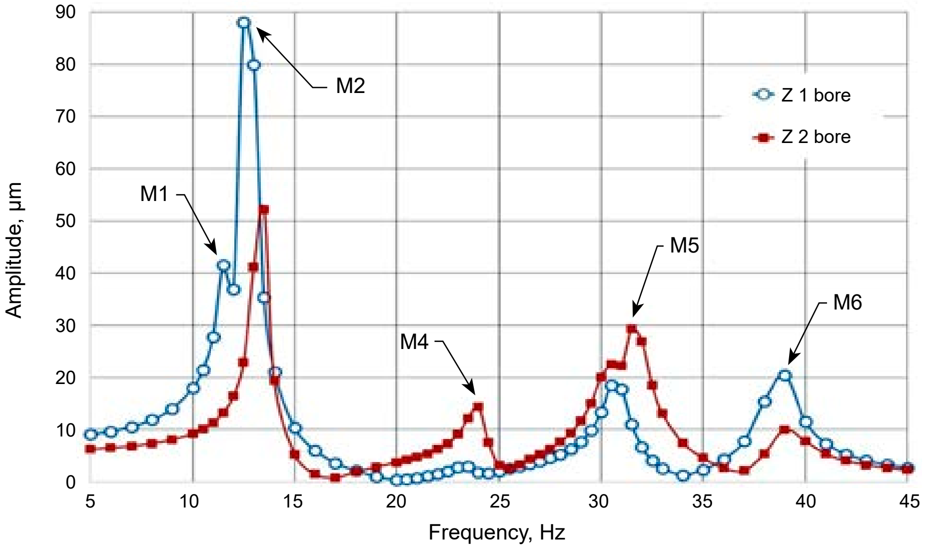


Figure 7. Axial boring spindle FRF (spindle force F_z^d along Z – spindle displacement along Z) for structures: "Monocolumn" (Z 1 bore) and "Portal" (Z 1 bore)

force F_z^d in Z direction only by the developed effect of oscillation crossing. The portal FRF ("Z 2 bore") has no definite M1 peak. Thus, portal configuration alleviates crossing effect. This is useful for cutting process precision and stability.

Discussion

Simulation has shown the portal structure ability to damp effectively low frequency, rough resonances M1–M4. It is not dependent on the cutting force current direction. Also, torsional resonance M3 alleviation is the most valuable feature of the "Portal" configuration. Resonant stock pecking is restrained differently by columns-to-portal coupling. No one peak is weakened for the set of "M5a, M5b, M6a, M6b" peaks The portal withstands effectively only if stock skewing is forced from X and Y directions. Axial (Z) ram oscillations (consisting of M5, M6 eigenmodes) are ambivalent to monocolumn and portal structures. As well, high-frequency ram bending (M7, M8) is not influenced by changes in machine tool configuration. The portal should be created if cutting is intermittent, with leading force harmonics at frequencies ≤ 40 Hz. Ram Z-oscillation may be counterbalanced by additional harmonic moment from the drive Z motor. Such intellectual functions are included in options for modern CNC systems.

Conclusions

Left to right monocolumns coupling into portal have enhanced spindle static rigidity by 1.91, 1.49, 1.39 times along X, Y, Z axes (for RHS case), respectively. A rigidity level of at least 118 N/µm is provided for most flexible direction X (with fully advanced ram).

Monocolumn-to-portal joining influences the eigenmode pattern which is a little concerning as frequencies shape the resonance. Whole-machine eigenmodes remain the same. The portal structure creation significantly damps resonance peaks M1, M2, M3, M4 (range 12–38 Hz) by 1.7–2.9 times. Dynamic rigidity doubles (204%) for the most dangerous, torsional resonance M3 (24.04 Hz). The portal structure may be ineffective for higher frequency resonances, tied with axial oscillation (M5, M6) and ram bending (M7, M8) inside the stock. Due to main FRFs peak lowering, the portal structure allows *resonance overriding* (*RovR*) for all whole-machine resonances. This means admissibility to machine workpieces just at resonance frequencies in all investigated range from 0 to 89 Hz. Intermittent cutting excitation on M1–M4 frequencies does not lead to the portal losing critical rigidity, as well as cutting auto-oscillation.

Monocolumn-to-portal transition reduces the crossing of oscillation between the X and Y direction. It is important to secure the diametrical accuracy of workpiece holes. Coupling monocolumns into the portal is recommended to decrease machine tool vibrations if technological force frequencies are below 40 Hz. If intermittent cutting is speedier, monocolumns with raised high stock become more stable itself for the effect of post-resonance damping. There is no need for additional reinforcement of such a column.

References

1. Herrero, A. & Bueno, R. (2001) *Development of the three axes travelling column ultraprecision milling machine*. 10th International Conference on precision engineering in Iokohama: Initiatives of precision engineering at the beginning of the millennium, pp. 529–533. Japan.
2. Jafarzadeh, E. & Movahhedy, M.R. (2017) Numerical simulation of interaction of mode coupling and regenerative chatter in machining. *Journal of Manufacturing Processes* 27, pp. 252–260.
3. López De Lacalle, L.N. & Lamikiz, A. (Eds.) (2008) *Machine Tools for High Performance Machining*. London: Springer-Verlag.
4. Lu, K., Lian, Z., Gu, F. & Liu, H. (2018) Model-based chatter stability prediction and detection for the turning of the flexible workpiece. *Mechanical Systems and Signal Processing* 100, pp. 814–826.
5. Muhammad, B.B., Wan, M., Feng, J. & Zhang, W.-H. (2017) Dynamic damping of machining vibration: a review. *International Journal of Advanced Manufacturing Technology* 89, pp. 2935–2952.
6. Munoa, J., Mancisidor, I., Loix, N., Uniarte, L.G., Barcena, R. & Zatarain M. (2013) Chatter suppression in the ram-type travelling column milling machines using biaxial inertial actuator. *CIRP Annals* 62 (1), pp. 407–410.
7. Olvera, D., López De Lacalle, L.N., Compean, F.I., Fz-Valdivielso, A., Lamikiz, A. & Campa, F.J. (2012) Analysis of tool tip radial stiffness of turn-milling centers. *International Journal of Advanced Manufacturing Technologies* 60, pp. 883–891.
8. Portentoso, M., Pennacchi, P. & Chatterton, S. (2017) Comparison of the dynamic response of two columns of milling machines made of standard carpentry and metal foam sandwiches. *Journal of Vibration and Control* 23 (17), pp. 2782–2794.
9. Stepan, G., Kiss, A.K., Ghalahamchi, B., Sopanen, J. & Bachrathy, D. (2017) Chatter avoidance in cutting highly flexible workpieces. *CIRP Annals* 66 (1), pp. 377–380.
10. Vasilevich, Y.V., Dounar, S.S. & Karabaniuk, I.A. (2016) Finite element analysis of concrete filler influence on dynamic rigidity of heavy machine tool portal. *Science & Technique* 15 (3), pp. 233–241.
11. Vasilevich, Y.V., Dovnar, S.S., Truskovsky, A.S. & Shumsky, I.I. (2015) Modelling and analysis of dynamics in bearing system of drilling, milling and boring machine with mono-column. *Science & Technique* 3, pp. 9–19.
12. Zienkiewicz, O.C. & Taylor, R.L. (2000) *The finite element method. Volume 1, Basis*. Oxford, Boston: Butterworth-Heinemann.

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