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UDC 621.9.011:517.962.1

FEA-ANALYSIS OF THE COUPLED PORTAL STRUCTURE IN THE LARGE HORIZONTAL MILLING MACHINE

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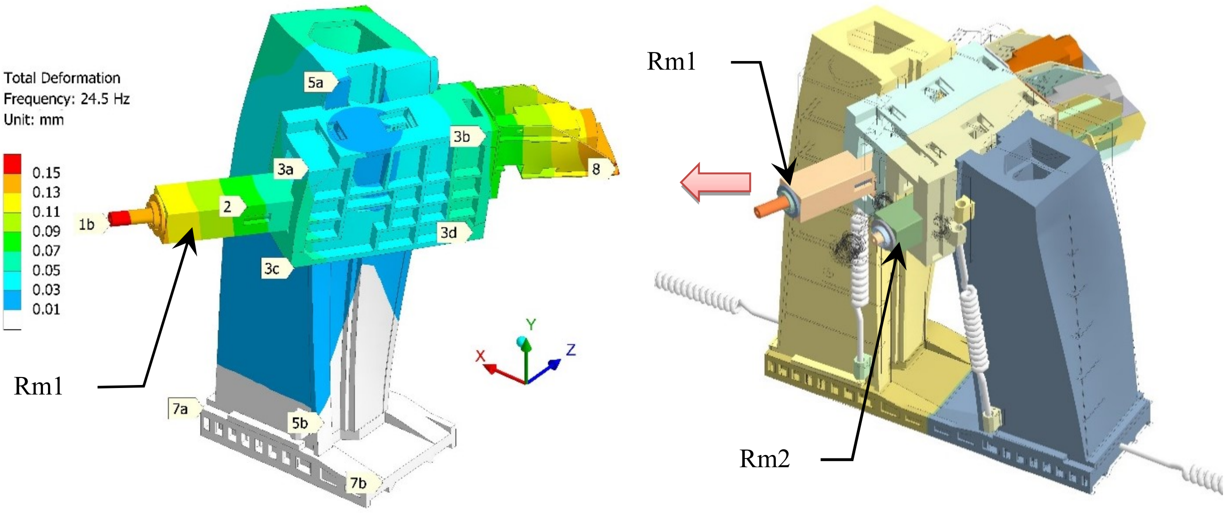
This work relates with renovation project touching group of «Travelling column» machine tools. Comparison between two configurations of machine tool – «Monocolumn» (fig. 1, a) and «Portal» (fig. 1, b) – is provided. Just situative coupled portal is mean. It may be created for the necessary time by two monocolumns moving close together and interlocking. Other time every column may move alone, according to its own CNC programs (fig. 2).

A column with the ram Rm1 is depicted at fig. 1, a. This column touches its paired column with ram Rm2 at fig. 1, b. Monocolumn (fig.1, a) provides cutting by double spindle unit (at the left end of ram Rm1). Boring spindle 1b may advance axially (along Z) up to 2.6 m. That range is provided partly by ram axial advance. Ram side surfaces 2 are slipping in the hydrostatic guides inside stock 3. Corner areas of stock are marked 3a, 3b, 3c, 3d. Stock possess a vertical freedom degree (along Y) due to hydrostatic guides (5a – 5b) on column 5. The stock has moving range 4.25 m. The column is fixed to sledge 7, slipping along X by hydrostatic guides 7a – 7b. Spindles are driven by motor 8.



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)

The main problem of monocolumn is a low dynamic rigidity at spindle in the direction X. It is caused mainly by torsional resonance. Axis of torsion is vertical (parallel to Y). It migrates inside triangle 3a – 3b – 5a. Even small angle of torsion turns into big linear displacements at the ends of «1b – 8» line. Stock is placed on the right from column. Renovated machine group poses columns as of right design so of the left one.

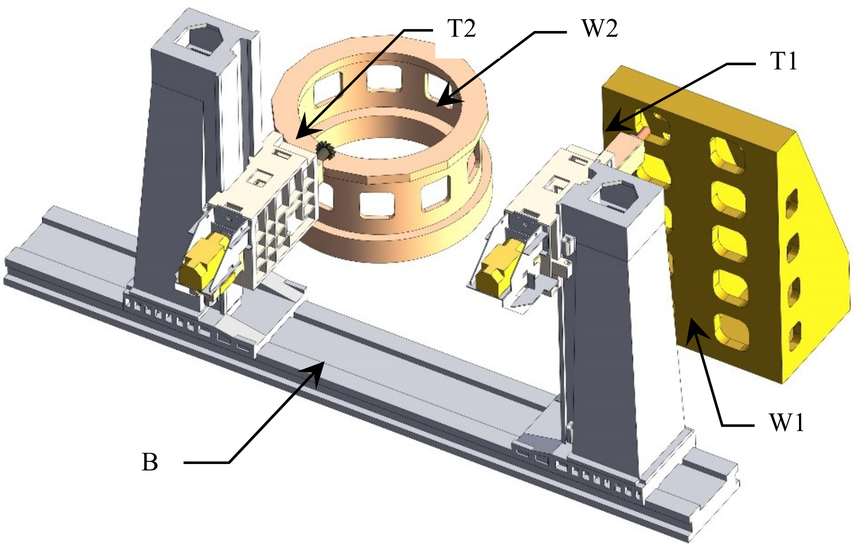


Figure 2 – Parallel machining of workpieces W1, W2 by tools T1, T2, placed at left and right monocolumns L, R (B – common bed)

During the renovation, it was proposed to install two monocolumn L and R (fig. 2) upon the bed with common guides. Columns may provide machining independently. Two diverse workpieces W1 and W2 (fig. 2) undergo separately boring and milling by tools T1 and T2. Feature of the presented configuration – one column has a right-side design (R) and second column – left-sided (L) one. Columns with stocks mirror each other. The configuration is convenient to provide collision-free two-ram machining of the large workpiece.

Main benefit from the presence of the mirroring columns would reveal in a critical case of rising high spindle (RHS) machining. Monocolumns of left and right design may be joined in the new load-bearing system – «Portal». Columns are to touch each other by stock sides and lock up. Double structure («Portal») poses additional static and dynamic rigidity when RHS cutting is provided.

The situative portal is represented as no monolithic contour. It poses inner slipping borders on hydrostatic guides.

Static testing force $F_{x,y,z}^{st} = 1kN$ was applied to the milling spindle end along coordinates X, Y, Z when the machine tool was in the RHS position. Simulated spindle displacements enable to calculate rigidity (tab.1). It is sufficient because is a higher then threshold level $\left[J_{x,y,z}^{thres}\right] = 20\,N/\mu m$ as for monocolumn so for portal structures.

Table 1. Static rigidity for «Monocolumn» and «Portal» along axes

Rigidity by axes, N/μm	Monocolumn	Portal	Rigidities ratio:
X	61.6	118.3	191%
Y	90.4	135.5	149%
Z	123.7	173.0	139%

Monocolumn spindle is most flexible in the X direction. It is due to stock-ram torsional movement about axis Y. Portal statically is a more rigid structure. Maximal difference (1.91 times) is revealed in the longitudinal direction X. In other directions portal is in one and half time stiffer than monocolumn.

Monocolumn poses different rigidities in the X, Y, Z directions (e.g. rigidity along Z in double exceeds one along X (tab. 1)). Portal demonstrates more stable behaviour. Directional rigidities differ no more, then 1.46 times.

Modal analysis disclosed a similarity of eigenmodes patterns for «Monocolumn» and «Portal» configurations. Main resonance M1 and second one M2 proved to be «one-fourth wave» column oscillations in the X and Z directions respectively. Eigenmode M1 include sledge reciprocation along X. However, column bending is here the dominant movement.

Eigenmode M3 depicted above. Mode M4 excitement leads mainly to ram-stock pecking. 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. That's modes should be damped or omitted. Ram pecking is caused by stock and Y-guides collective skewing. Eigenmodes M1 – M6 excitation embrace all machine tool (whole-machine resonances). Modes M1 – M4 pertain to low-frequency interval and M5 – M6 to middle-frequency one. Modes M7 – M8 relates to local and high-frequency resonances.

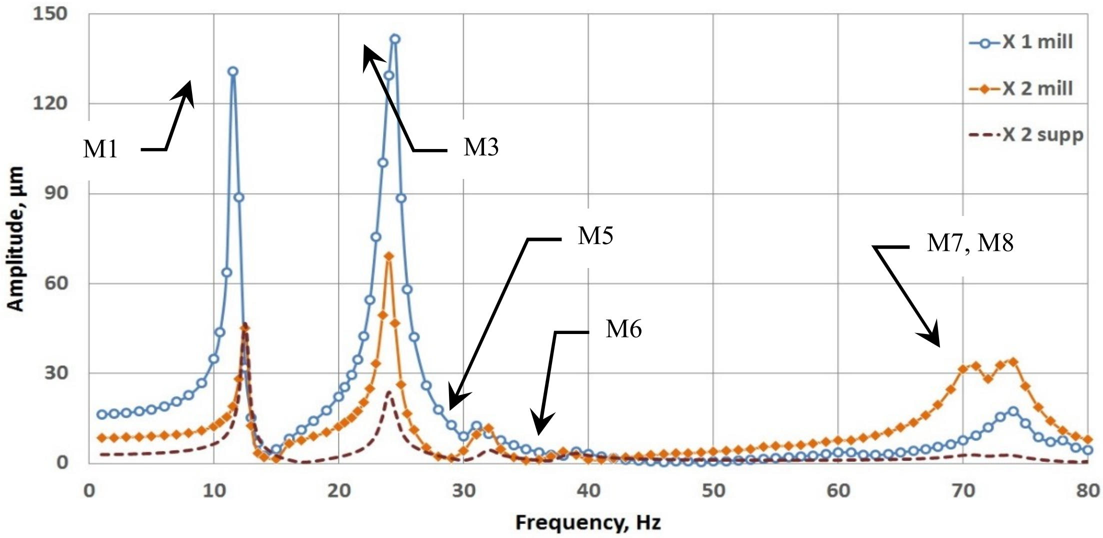


Figure 5 – Milling spindle longitudinal FRF (spindle force F_x^d along X – spindle face displacement along X) for monocolumn (X 1 mill) and portal (X 2 mill)

Pair of milling spindle FRF's are represented on fig.5 for the case of longitudinal (X) excitation. Curve «X 1 mill» relates to monocolumn structure and curve «X 2 mill» – to the portal one. Curve «X 2 supp» presents a supporting face (at stock) amplitude. Leverage effect of long ram is absent her. So curve «X 2 supp» describes column movements and is the lowest on the picture.

FRF on the fig. 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. Range from ~35 to ~65 Hz seems to be very calm and appropriate for intermittent cutting.

The main conclusion from FRF at fig.5 – monocolumn-to-portal transition effectively reduces resonance peaks, thus only for whole-machine resonances. Spindle amplitude is lowering in 2.9 times for bending eigenmode M1 and in 2.04 times – for torsional mode M3.

Conclusions.

Monocolumns coupling into portal have enhanced spindle static rigidity in 1.91 – 1.49 – 1.39 times relatively along X, Y, Z axes. Rigidity level at least 118N/µm is provided for most flexible direction X (with fully advanced ram).

Monocolumns-to-portal joining influences the eigenmode pattern a little concerning as frequencies so resonance shapes.

Portal structure creation significantly damps resonance peaks M1, M2, M3, M4 (range 12-38 Hz) in 1.7 – 2.9 times. Dynamic rigidity doubles (204%) for most dangerous, torsional resonance M3 (24.04 Hz). The portal structure may be ineffective for higher frequency resonances.

Due to main FRF's peak lowering, the portal structure allows resonance overriding for all whole-machine resonances. It means admissibility to machine workpieces just at resonance frequencies in range from 0 to 89 Hz.

Monocolumns-to-portal transition reduces the crossing of oscillation between X and Y direction. It is important to secure the diametrical accuracy.

Coupling monocolumns into the portal is recommended to decrease machine tool vibrations if technological force frequencies are below 40 Hz. If cutting is more speedy, there is no need in additional reinforcement of monocolumn.

UDC 621.9.011:517.962.1

FEA-AUDIT AND REDESIGN OF PRACTICE-PROVED CENTRIFUGE MACHINE

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Given work touches the compact, high-speed biological centrifugal machine, designed before FEA epoch, but permanently produced and exploited till now. So some kind of FEA-audit of old, intuitive design is provided here. Proportions of centrifuge load-bearing system (LBS) are optimized and proved by long-term practice. Collapses and partial cracking are not reported for all centrifuge examples.

The centrifuge works in the quasi-static mode with long time loading by constant centrifugal forces caused by stable rotation at the speed 4000 min^{-1}. Quantity of loading cycles (due to speeding up and running out) is not large for all service life. So static strength and, possibly, ratcheting (during low-cycle fatigue) are the main issues.

Some specific terms are proposed for explanations here below:

Critical point of surviving (CPS) – severe stress concentrator possesses next features simultaneously: a) almost inevitable in the design sense; b) haven't got a reservation if cracked; c) shortage of effective parameters to control the level of stress in it. It is obvious that CPS tied to different inner corners and fillets.

Fillet radius management (FRM) – need to vary fillet radius for CPS smoothing, causing no indirect damages and harmful consequences for nearby design.

Controllable contact spot control (CSC) – design approach aiming to reduce nominal contact interface to dimensions of expected virtual contact spot.

Fig. 1, a gives an outer view of the centrifuge's LBS. Fig.1, b depicts 1/6 portion of the full model. The section view on the rotating structural parts is given in fig.2. The set of parts consists of the aluminum rotor 1 (ø205 mm; six spokes 1S protruded radially from the hub 1H) and six aluminum cups 2 (height 162 mm), containing processed liquids in the flexible envelopes. Envelopes are replaced by weights 3. There is lug 1L at the end of each spoke. Lug holds steel pin 4.