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Substituting a Conventional Ram Frame with a Sandwich Structure

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Abstract. The main goal is to determine if a sandwich structure (with steel sheets as outer plates and aluminium foam as filler) is suitable for a ram in an overhead gantry. The main expected features of the new design are fewer deformations, lower weight and natural frequencies than the current solution. A semi-circular sandwich structure in two thickness variants (V1) and (V2) will be implemented into the adjusted frame. It is also necessary to keep in mind the possibility of mounting the sandwich structure into the adjusted frame. Comparative analysis was done to determine if and how the new design is better than the current solution. The primary tools used for the comparison are modal analysis and static analysis for several states.

Introduction

Strong competition between machine tool manufacturers is the driving force behind innovations. Therefore it is necessary to develop and improve current solutions used in machine tools. One of the main component groups of machine tools are rams. The main feature of a ram is to hold the machining head which is connected to the ram by bolts on a circular flange and afterwards connected with other parts of whole machine tools. The slide is connected to the ram and performs horizontal transverse movements. Longitudinal movements are performed by a crossbeam which is placed on two supports which transfers all the loads to the base. Sleeve bearings connect the basic parts of the machine tool. Basic outer dimensions of the whole machine tool are (l x w x h) 10100 mm x 5280 mm x 7112 mm. Dimensions of the fixing desk are 6200 mm x 2670 mm.

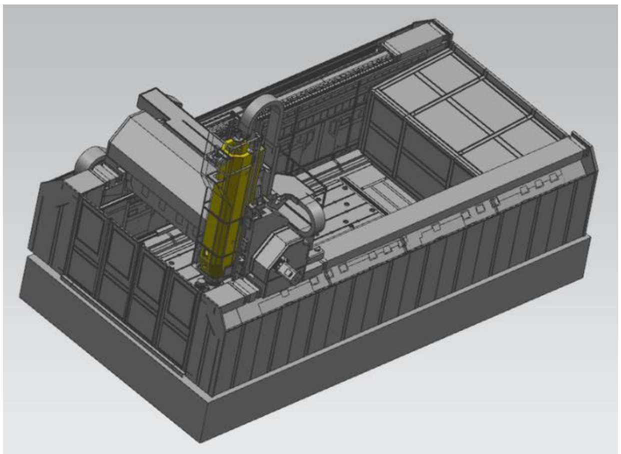

Fig.15 Overhead gantry with ram (in yellow)

The ram performs vertical movements in a defined range. Furthermore, the ram is another part of a machine tool for which it is possible to use the advantages of sandwich materials, such as high bending stiffness, low weight and vibration damping. Several approaches for implementing sandwich materials will be shown. The approaches will be verified by simulations, which will be performed on a conventional frame and on the newly designed frame.

Material selection for designing a sandwich structure

A sandwich material composed from two steel sheets as outer plates and aluminium foam filling was selected for the design. Steel sheets were selected considering the connection with the rest of the frame by various methods including welding. The main advantages of aluminium foam are high stiffness, low density, high toughness, corrosion resistance and very good vibration damping. Aluminium foam can be used not only for sandwich structures but also for filling more complex products such as cast engine brackets.

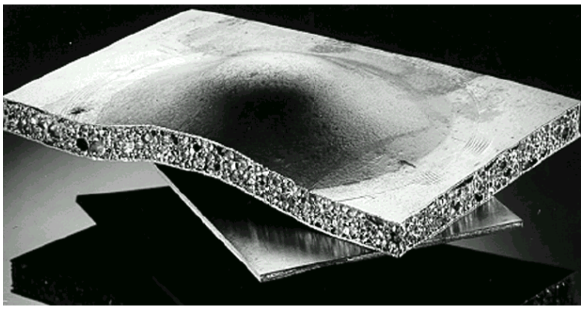

Fig.16 Sandwich material composed from two steel sheets and aluminium foam [2]

Foam can be prepared in several ways. It is a very porous material and its structure is similar to natural structures such as bone and coral. Cellular structures have relatively high stiffness. In comparison with other metal foams aluminium foam has many advantages, as mentioned above. The principle is to create bubbles in the melt and then cool the melt. There are two main types of alloys for manufacturing the foam – alloys that are suitable for casting and alloys that are suitable for forming. The first have smaller, irregular shaped pores, the walls are thin and the structure is non-uniform. Alloys suitable for forming create foams with spherical pores and the walls are thicker. Bubbles can be created as a result of melting the semiproduct, which contains a frother. Another way is to blast gas into the melt from an external gas reservoir. Thermal decomposition of added frother in the melt is also possible. When the melt has low viscosity, the resultant foam contains bigger spherical pores, which rise to the surface. The tendency is to create smaller pores. Manufacturers of aluminium foams include LKR, Cymat and Shinko Wire Company.

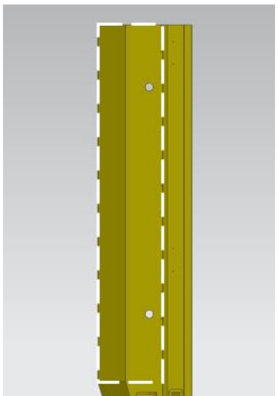

Fig.17 Conventional ram with area to be replaced by sandwich structure (white dashed line)

Principle of substitution

The objective is to use sandwich material in the area shown in **Chyba! Nenalezen zdroj odkazů.**. The area is composed from inner and outer steel sheet envelopes which are connected to each other by ribs with various thickness. The weight of the existing frame is 2640 kg. The dimensions of the frame are (l x w x h) 705 mm x 620 mm x 3000 mm. The new design of the frame should preserve these dimensions to ensure the simple replacement of the conventional frame with the new

design, which is without the struts and instead has a sandwich panel. The new design is adjusted in the modified area for placing the sandwich structure in grooves. The sandwich panel is fixed above by a steel element with the same groove. The adjusted frame, sandwich panel and upper element are connected to each other by welding. This is shown in yellow in **Chyba! Nenalezen zdroj odkazů.**.

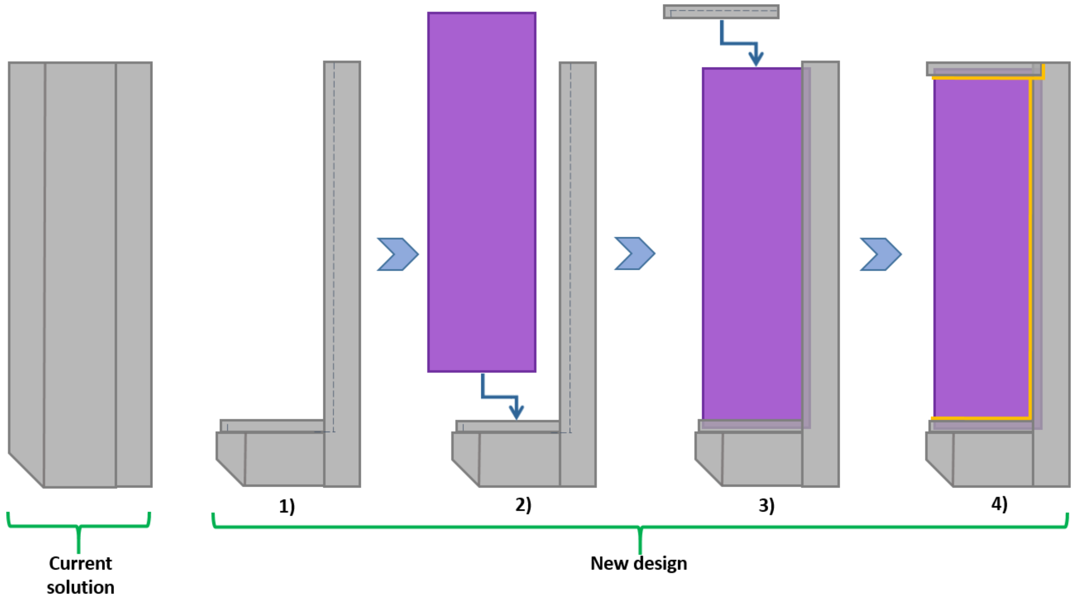

Fig.18 Diagram of current solution and new design including manufacturing steps

The sandwich panel is composed from two bent steel sheets as outer plates and filled with aluminium foam. The new design is slightly different from the current state and its profile is semi-circular. This profile is good for manufacturing because there are no other connections. The sandwich plate is completely implemented as one part. Small holes and hollows are not taken into consideration during the following simulations due to their small influence on the final results. Two versions of the new design are tested – V1 and V2. These variants have different layer thicknesses. V1 is (outer plate – filler – outer plate) 5mm – 10mm – 5mm. V2 is (outer plate – filler – outer plate) 12mm – 26mm – 12mm. Total wall thickness in the current state is 85mm, so wall thicknesses are about 76 % (V1) and 41% (V2) thinner.

Preparing the models of conventional and new frames

Conventional frame

First, modal analysis and static analysis were performed and these results are compared with the new designs. CTETRA4 with element size 25mm with the possibility of local refinement was selected as the mesh. For modal analysis, the model was not fixed and not loaded. Static simulation was carried out for minimum and maximum overhang and with a load (1000N) on two axes in the horizontal plane.

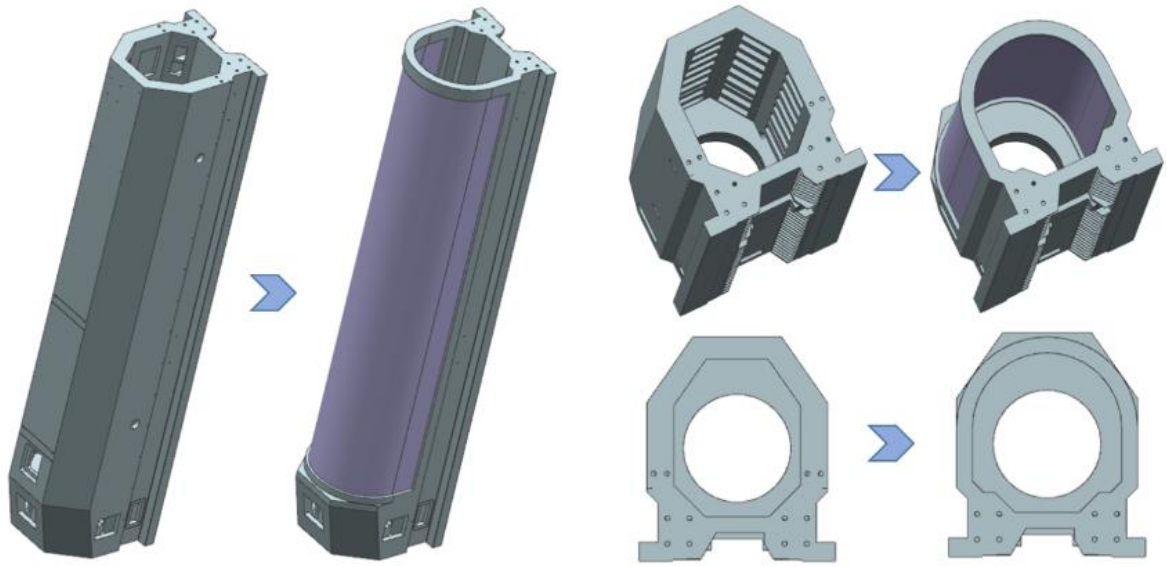

Fig.19 Comparison of current and new frame

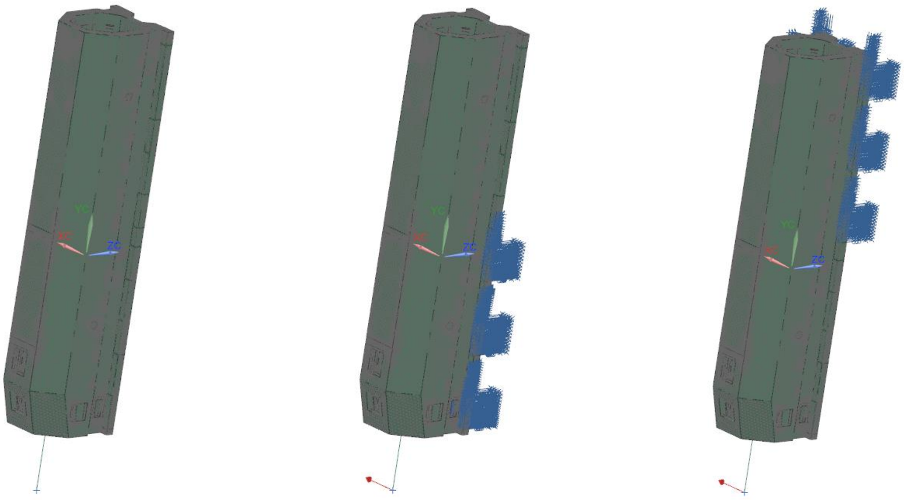

Fig.20 Computational models of conventional frame. (Left) modal analysis; (middle) static analysis - low overhang; (right) static analysis - high overhang

New design – V1 and V2

The sandwich material was defined by a laminate modeller (Siemens NX), which means that the sandwich structure was modelled as two 2D faces. First, both 2D faces ware meshed by a 2D dependent mesh with 25mm elements to ensure the defined layer composition between those two faces is filled. Thicknesses of layers were modelled in two variants – thinner (V1) and thicker (V2). V1 is composed of 5 mm steel sheets for the outer layers and 10 mm aluminium foam (Density 400 kg/m^3, Young´s Modulus 2374 MPa, Poisson´s Ratio 0.29) as filler. V2 is composed from 12 mm steel sheets for the outer layers and 36 mm of aluminium foam. The rest of the frame was adjusted by cutting and removing the conventional struts in the modified area. The grooves and the upper element, mentioned above, were modelled in this area. All these adjustments create one integral part. The outer steel sheets of the resultant sandwich panel are connected to the adjusted frame by Surface-To-Surface Gluing. This is a simplifying element which substitutes for the connection by welding.

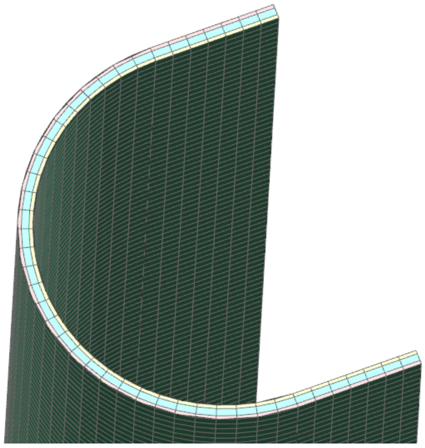

Fig.21 Layer composition of sandwich panel
Figure 22 Computational models of V1 and V2 frames. (left) modal analysis; (middle and right) static analysis - low overhang and high overhang

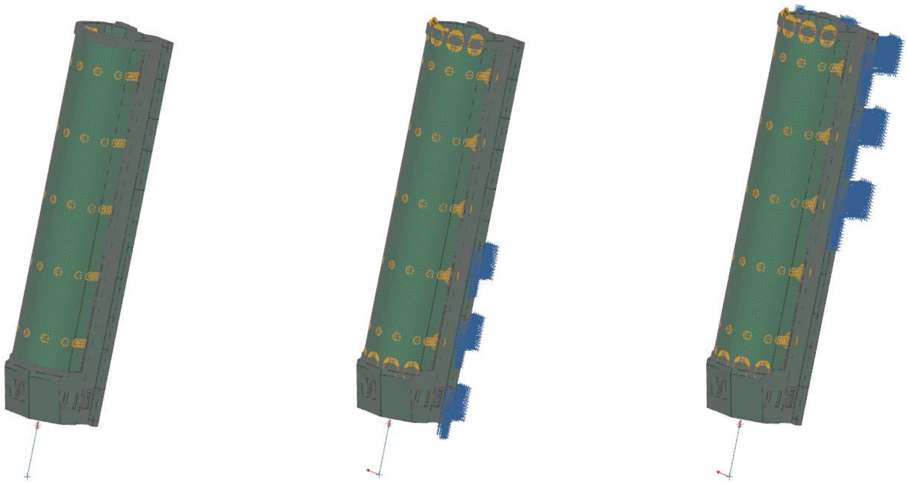

Fig.23 Computational models of V1 and V2 frames. (left) modal analysis; (middle and right) static analysis - low overhang and high overhang

Results

The results of the modal and static analysis are used as reference results for the following evaluation of the new designs. Fig.24 shows the first four natural frequencies and Fig.26 shows the results of static analysis. The same results are also shown for the modified variant V2 - Fig.25 shows natural frequencies and Fig.27 shows static analysis. Only V2 was selected because its results are more similar to the current solution. The first 10 natural frequencies for each design (current frame, V1 and V2) were simulated and four loading states were prepared for each design. In general, the resultant natural frequencies of modal analysis for V1 have lower values than the conventional frame over the whole range. The deformations of V1 are better only for a low overhang. The high overhang shows bigger differences and the conventional frame has less deformation for this state. The main advantage of V1 is that it is about 25% lighter. Variant V2 has modes of modal analysis almost the same as the conventional solution. This is a desired feature. In general, modes of modal analysis for V1 have lower values than the conventional frame over the whole range. Deformations of V1 are better for low overhang. High overhang shows bigger differences and the conventional frame has lower deformations for this state. The main advantage of V1 is that it is about 25% lighter. Variant V2 has modes of modal analysis almost the same as the conventional solution. The biggest difference is in mode 6, which is about 17%. Deformations are lower from 1 to 13% for all states. It is more than 10% lighter. In absolute terms, this means a saving of 266 kg.

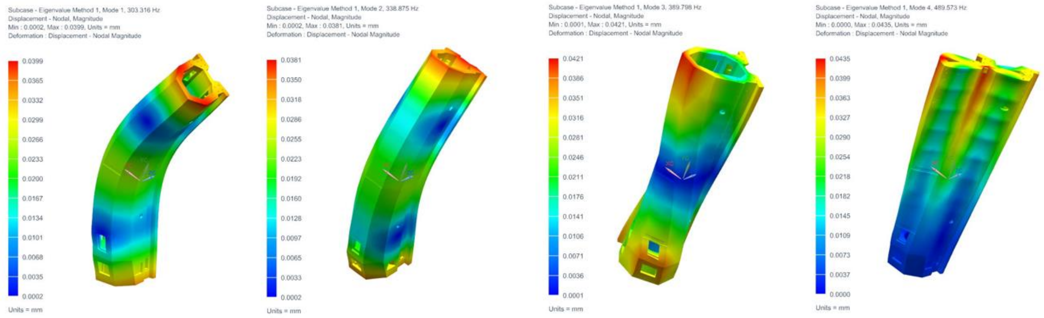

Fig.24 Results: Modal analysis of conventional frame with directions of first 4 natural frequencies

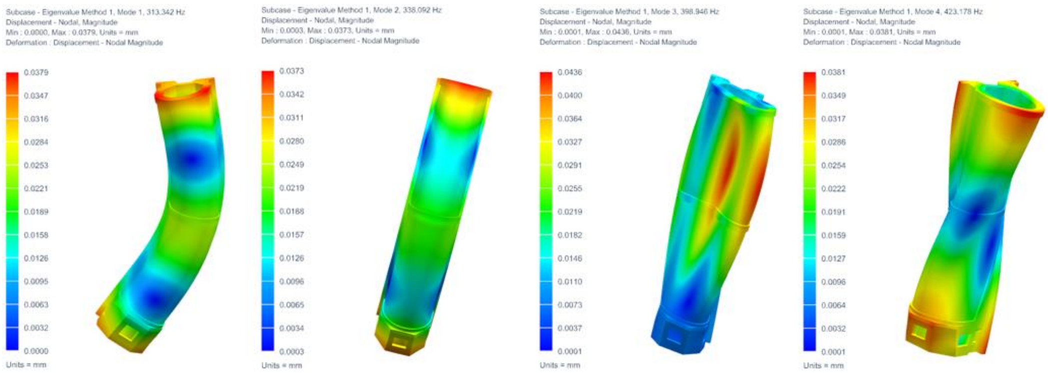

Fig.25 Results: Modal analysis of new design V2 with directions of first 4 natural frequencies

Tab.18 Comparison of results – natural frequencies

	CURRENT SOLUTION	V1		V2	
MODE	**VALUE (HZ)**	**VALUE (HZ)**	**DIFFERENCE (%) (V1 VS. CURRENT)**	**VALUE (HZ)**	**DIFFERENCE (%) (V2 VS. CURRENT)**
1	1. 303.3	2. 277.9	**3. -8.4**	4. 313.3	**5. 3.3**
2	6. 338.9	7. 311.8	**8. -8.0**	9. 338.1	**10. -0.2**
3	11. 389.8	12. 323.6	**13. -17.0**	14. 399.0	**15. 2.4**
4	16. 489.6	17. 359.8	**18. -26.5**	19. 423.2	**20. -13.6**
5	21. 535.5	22. 363.7	**23. -32.1**	24. 462.9	**25. -13.6**
6	26. 566.1	27. 407.3	**28. -28.1**	29. 468.0	**30. -17.3**
7	31. 602.5	32. 426.3	**33. -29.2**	34. 524.5	**35. -12.9**
8	36. 623.9	37. 532.9	**38. -14.6**	39. 612.5	**40. -1.8**
9	41. 652.4	42. 545.8	**43. -16.3**	44. 643.1	**45. -1.4**
10	46. 712.3	47. 664.6	**48. -6.7**	49. 671.9	**50. -5.7**

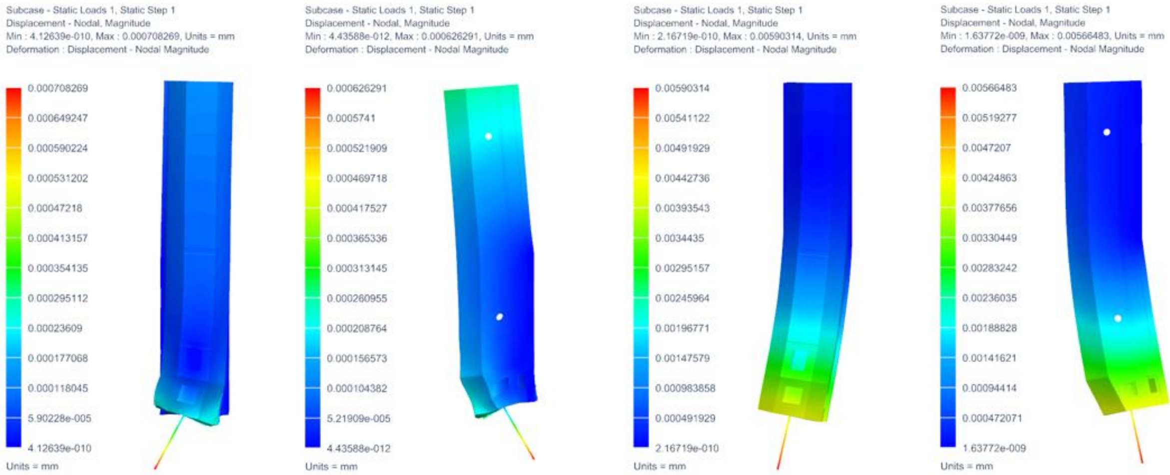

Fig.26 Results: Static analysis of conventional frame. From left: 1) low overhang, load in X direction, 2) low overhang, load in Z direction; 3) high overhang, load in X direction; 4) high overhang, load in Z direction

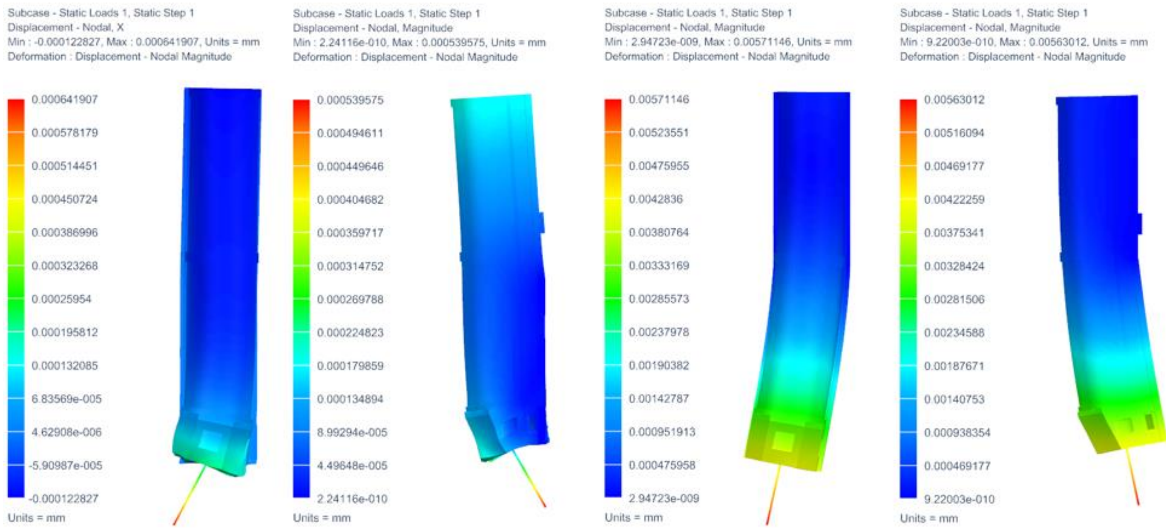

Fig.27 Results: Static analysis of new design V2. From left: 1) low overhang, load in X direction, 2) low overhang, load in Z direction; 3) high overhang, load in X direction; 4) high overhang, load in Z direction

Tab.19 Comparison of results - static analysis and weight

	MINIMUM OVERHANG (mm) Max Deformation X	MINIMUM OVERHANG (mm) Max Deformation Y	MAXIMUM OVERHANG (mm) Max Deformation X	MAXIMUM OVERHANG (mm) Max Deformation Y	Total weight (kg)
Conventional frame	0.000708	0.000626	0.005903	0.005665	2641.1
V1	0.000688	0.000622	0.006593	0.007523	1949.4
V2	0.000642	0.00054	0.005711	0.00563	2375.4
DIFFERENCE (%) Conventional vs. V1	**-2.8**	**-0.6**	**11.7**	**32.8**	**-26.19**
DIFFERENCE (%) Conventional vs. V2	**-9.3**	**-13.7**	**-3.3**	**-0.6**	**-10.06**

Conclusion

This article deals with the comparison of a conventional ram frame and an alternative construction, which is composed of sandwich material. Two variants of the new design with aluminium foam filler were simulated. Simulations confirmed that this material is useable for similar operations as the conventional ram. Substitution of the conventional design in the ram with similar natural frequencies and lower weight and deformations is possible by using variant V2. The method is also applicable for previously manufactured conventional frames which can be also adjusted as mentioned above. In general terms, the method cannot be prepared without simulations of a virtual frame. Substitution cannot be based only on estimation. There are still opportunities for optimization. The frame could be reinforced by several struts designed around the sandwich panel which would mean that the steel panels of the sandwich panel would be thinner, ensuring lower final weight. The next step is to compare other shapes of sandwich plates with the synergy of struts to reinforce the structure and investigate these influences on the results. Another way is to replace the material of the outer plates. Aluminium sheet can be used instead of steel sheet. In this case, connection by bolts or glue is better. Investigations will mainly focus on the reduction of weight, resultant deformation, preservation of current natural frequencies and manufacturing costs. The optimized ram will also be tested on a whole machine tool. Other parts of the machine tool will be the same. The results from this simulation will also be dependent on the correct design of the slide assembly. These results will be more important because the new design should be usable mainly for a complete machine tool and its cutting conditions.

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