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Substituting a conventional ram frame with a variants of 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 equal or higher natural frequencies than the current solution. A flat semi-circular sandwich structure, wrinkled (horizontal and vertical) semi-circular sandwich structure and angular-shaped sandwich structure 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 were 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, static analysis and frequency response 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. 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.

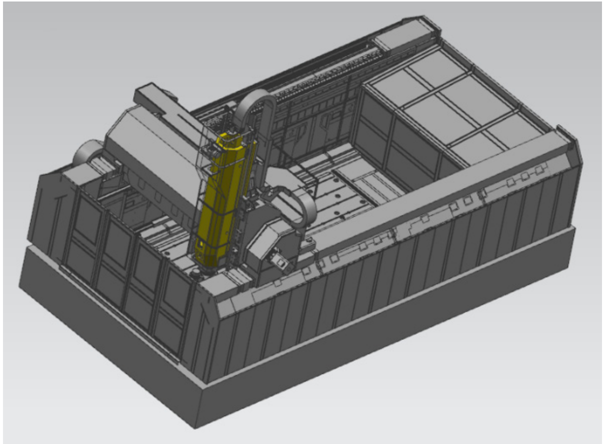

Figure 1 Overhead gantry with ram (in yellow)

Material selection for designing a sandwich structure

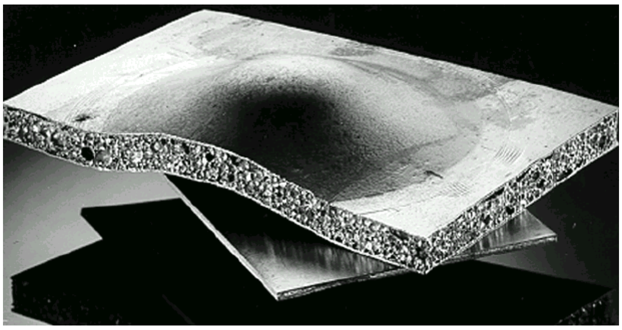

Figure 2 Sandwich material composed from two steel sheets and aluminium foam [2]

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. 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.

Principle of substitution

The objective is to use sandwich material in the area shown in Figure 3. 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. Grooves are adjusted to each design. The adjusted frame, sandwich panel and upper element are connected to each other by welding. This is shown in yellow in Figure 4. The sandwich panel is principally composed from two bent steel sheets as outer plates and filled with aluminium foam. The series of new designs are slightly different from the current state and its profile are semi-circular, semi-circular with wrinkles (horizontal and vertical) and angular. Semi-circular flat profile and angular profile are the best for manufacturing because of the simplest shape. The sandwich

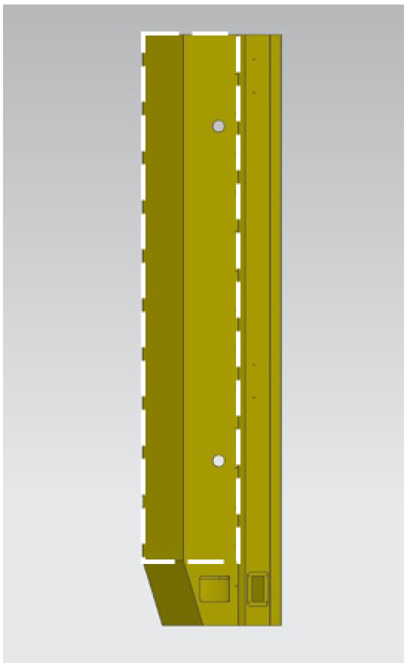

Figure 3 Conventional ram with area to be replaced by sandwich structure (white dashed line)

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. Four versions of the new design are tested – V1, V2, V3 and V4. These variants have different shape and design but the same layer thicknesses. V1 has flat semi-circular profile, V2 has horizontally wrinkled semi-circular profile, V3 has angular shape profile and V4 has vertically wrinkled semi-circular profile. Total wall thickness in the current state is 85mm, newly designed composition is 50mm thick so wall thicknesses are about 41% thinner.

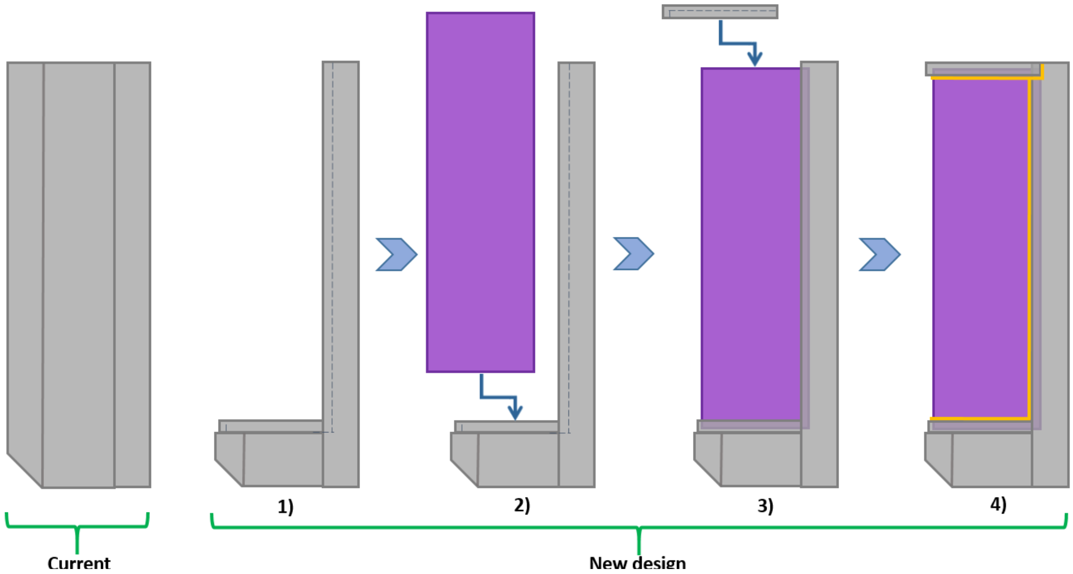

Figure 4 Diagram of current solution and new design including manufacturing steps

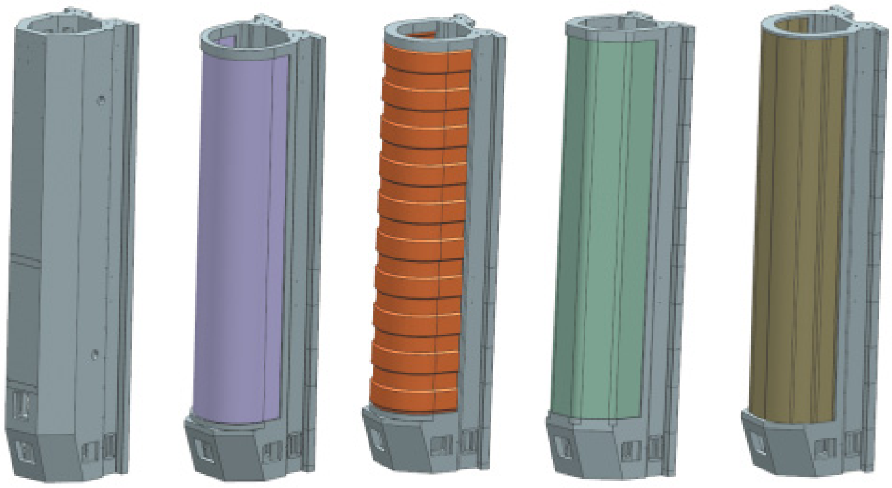

Figure 5 Comparison of current and new frames (from left: current, V1, V2, V3, V4)

Preparing the models of conventional and new frames

Conventional frame

First, modal analysis, static and frequency response 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 fixed in maximal overhang 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. Frequency response was carried out for maximal overhang in whole range of frequencies of modal analysis for most suitable variant. Modal analysis was used as basis for frequencies range determination.

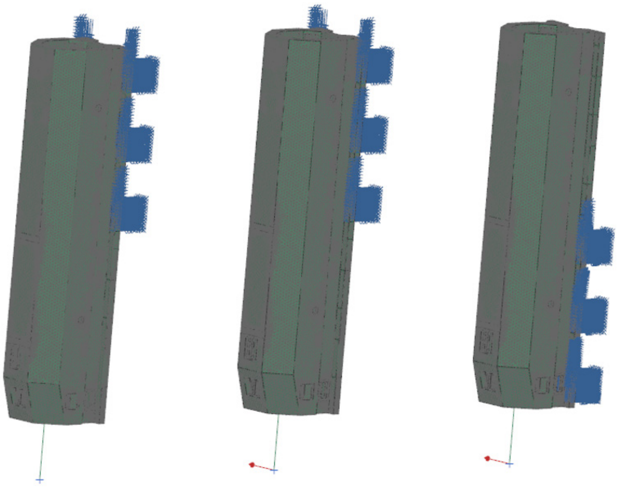

Figure 6 Computational models of conventional frame. (Left) modal analysis; (middle) static analysis and frequency response - high overhang; (right) static analysis - low overhang

New design – V1, V2, V3, V4

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 the same for all variants. It is composed of 12 mm steel sheets for the outer layers and 26 mm aluminium foam (Density 400 kg/m^3, Young´s Modulus 2374 MPa, Poisson´s Ratio 0.29) as filler. Total thickness is 50mm. 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.

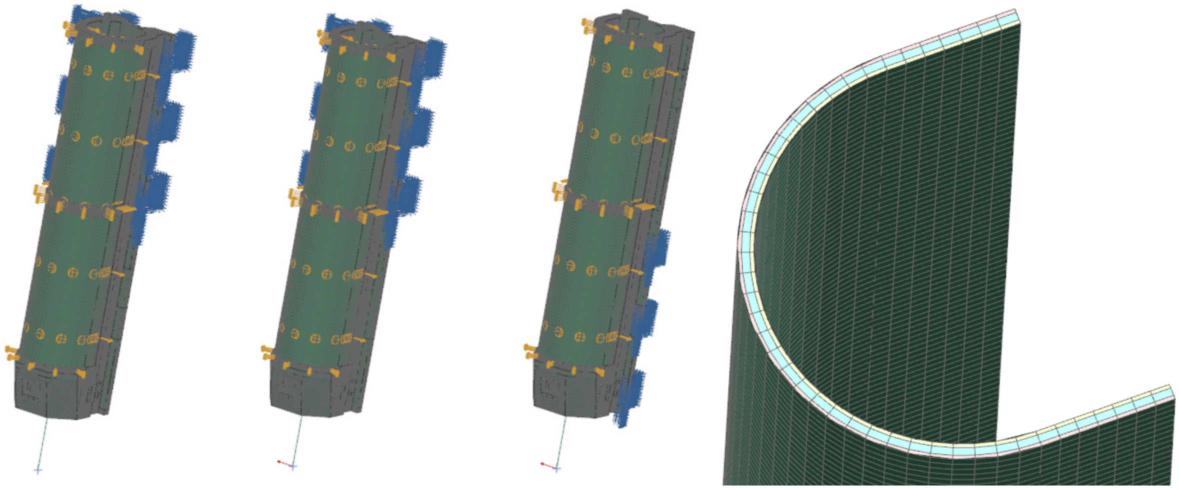

Figure 7 Left: Computational models of new designed frame – from left: modal analysis, static and harmonic analysis – high overhang, static analysis - low overhang; Right: Layer composition of sandwich panel

Results

The results of the modal, static and frequency response are used as reference results for the following evaluation of the new designs. Figure 8 shows the first four natural frequencies and Figure 11 shows the results of static analysis. The same results are also shown for the modified variant V4 - Figure 9 shows natural frequencies and Figure 10 shows static analysis. Only V4 was selected because its results are comprehensively most similar to the current solution. The first 10 natural frequencies for each design (current frame, V1, V2, V3, V4) were simulated and four loading states were prepared for each design. To verify how big displacements occur during modal analysis, frequency response for the most suitable was performed. In general, the resultant natural frequencies of modal analysis for V1 have lowest deviations in compare with the conventional frame. In general all new variants have lower deformations than conventional frame. The deformations of V4 are the lowest in compare with all another variants (average improvement is about 16% across all load states). This is main advantage of V4. It is also about 10% lighter. In absolute terms, this means a saving of 274 kg. Results of frequency response shows, that V4 has lower deformation in the most critical mode. It is the same mode as in conventional frame – mode 1. It is about 20% lower deformation than for conventional frame.

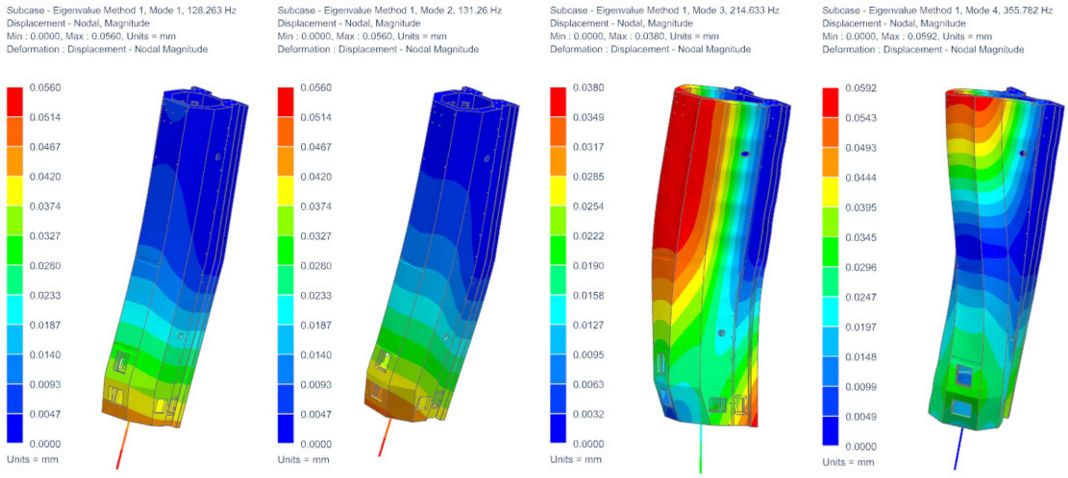

Figure 8 Results: Modal analysis of conventional frame with directions of first 4 natural frequencies

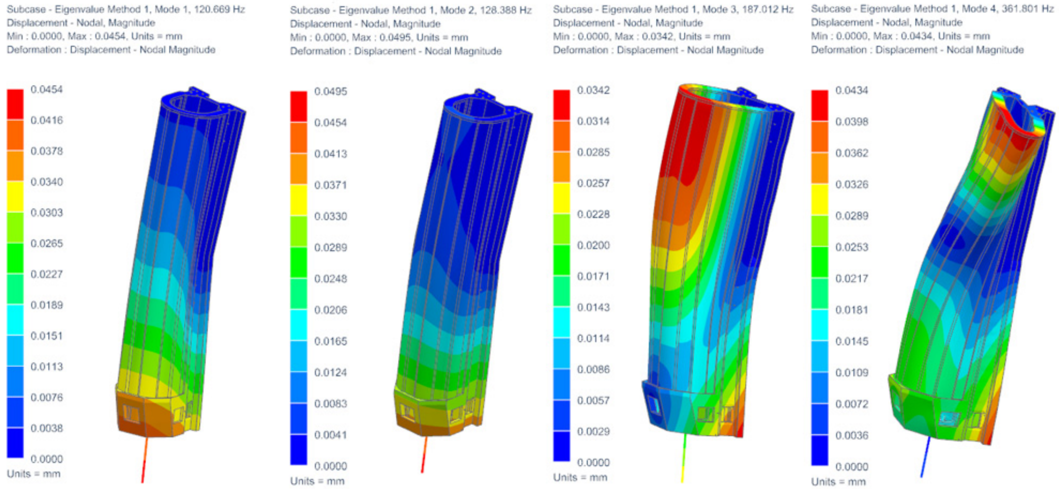

Figure 9 Results: Modal analysis of new design V4 with directions of first 4 natural frequencies

	CURRENT SOLUTION	V1		V2		V3		V4	
MODE	VALUE (HZ)	VALUE (HZ)	DIFFERENCE (%) (V1 VS. CURRENT)	VALUE (HZ)	DIFFERENCE (%) (V2 VS. CURRENT)	VALUE (HZ)	DIFFERENCE (%) (V3 VS. CURRENT)	VALUE (HZ)	DIFFERENCE (%) (V3 VS. CURRENT)
1	128.3	123.8	-3.5	116.7	-9.0	122.4	-4.6	120.7	-5.9
2	131.3	130.8	-0.4	117.5	-10.5	132	0.5	128.4	-2.2
3	214.6	196.5	-8.4	192.3	-10.4	177.6	-17.2	187	-12.9
4	355.8	364.7	2.5	364	2.3	335.5	-5.7	361.8	1.7
5	477.7	474	-0.8	445.5	-6.7	444.7	-6.9	459	-3.9
6	505.8	474.4	-6.2	463.5	-8.4	462.3	-8.6	471	-6.9
7	576.7	505.7	-12.3	489.3	-15.2	471.8	-18.2	472	-18.2
8	657.4	563.7	-14.3	559.7	-14.9	524.9	-20.2	535	-18.6
9	669.7	597.7	-10.8	582.8	-13.0	574.7	-14.2	584.5	-12.7
10	683.3	616.4	-9.8	588.9	-13.8	589.4	-13.7	603.7	-11.6

Table 1 Comparison of results – natural frequencies

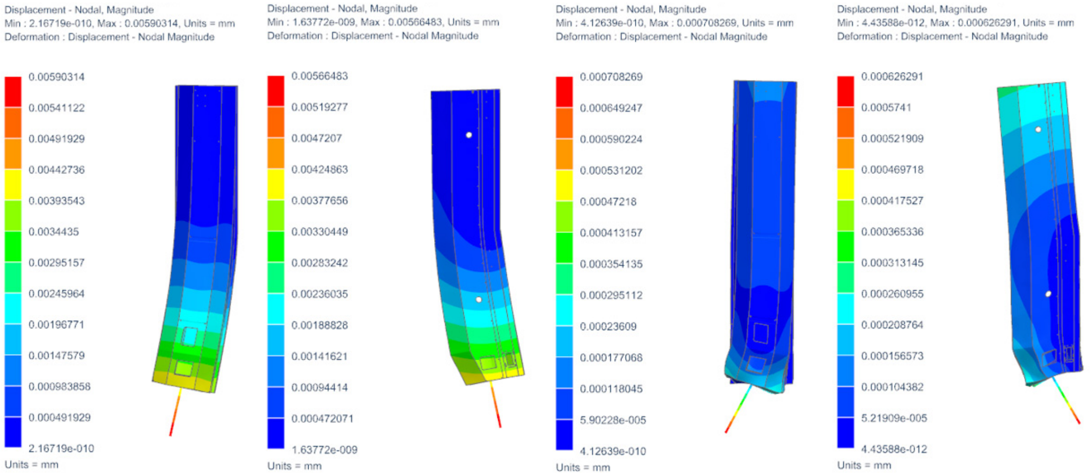

Figure 11 Results: Static analysis of conventional frame. From left: 1) low overhang, load in X direction, 2) low overhang, load in Z direction; 3) high overhang, load in X direction; 4) high overhang, load in Z direction

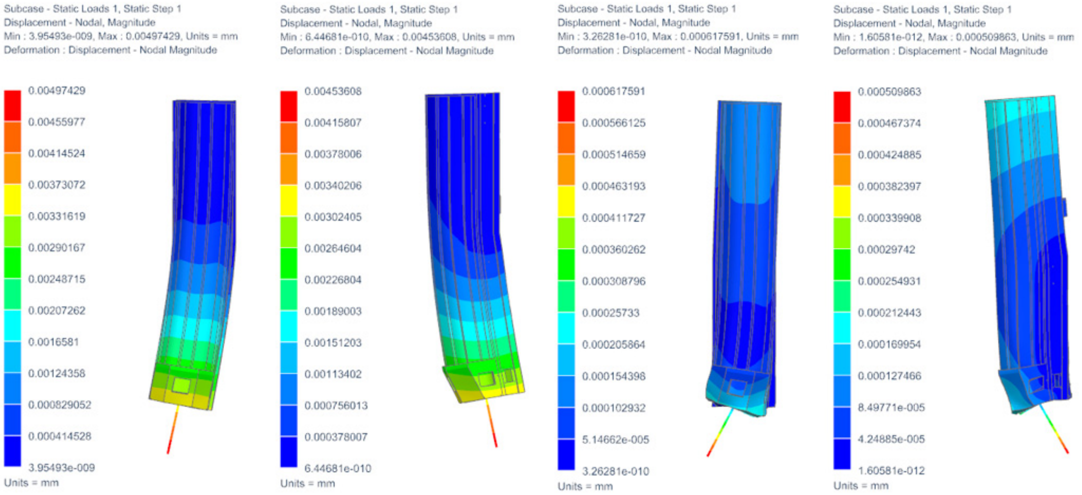

Figure 10 Results: Static analysis of new design V2. From left: 1) low overhang, load in X direction, 2) low overhang, load in Z direction; 3) high overhang, load in X direction; 4) high overhang, load in Z direction

	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	0.000642	0.000540	0.005711	0.005630	2356,3
V2	0.000645	0.00053	0.006017	0.005851	2343,2
V3	0.000685	0.000590	0.005591	0.005432	2336,3
V4	0.000620	0.000510	0.004970	0.004540	2367,4
DIFFERENCE (%) Conventional vs. V1	-9.3	-13.7	-3.3	-0.6	-10,8
DIFFERENCE (%) Conventional vs. V2	-8,9	-16,1	1,9	3,3	-11,3
DIFFERENCE (%) Conventional vs. V3	-3,2	-5,8	-5,3	-4,1	-11,5
DIFFERENCE (%) Conventional vs. V4	-12,4	-18,5	-15,8	-19,9	-10,4

Table 2 Comparison of results - static analysis and weight

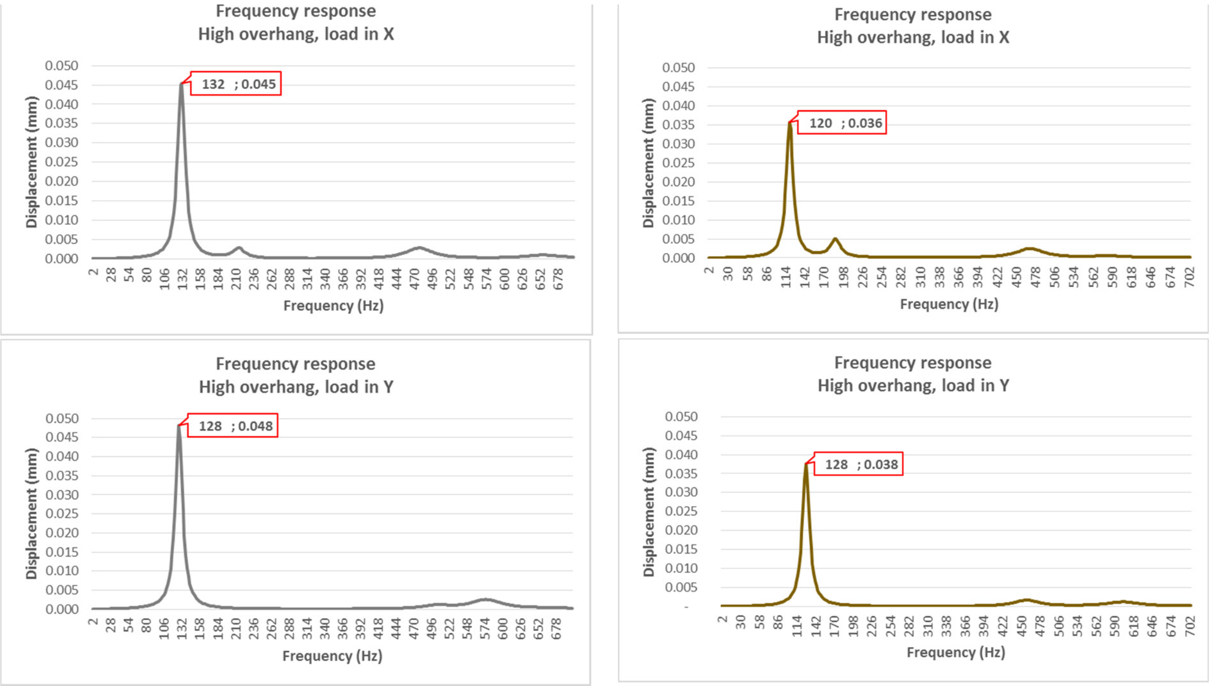

Figure 12 Results - frequency response; left top: Conventional frame, high overhang, load in X; right top: V4, high overhang, load in X; bottom left: Conventional frame, high overhang load in Y; bottom right: Conventional frame, high overhang, load in Y

Conclusion

This article deals with the comparison of a conventional ram frame and an alternative construction in several variants. They are composed of sandwich material. Four 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 mainly lower deformations is possible by using variant V4. 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. It would be the next step to use the 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 can be also tested on a whole machine tool. Other parts of the machine tool can be the same. These results will be also important because the new design should be usable mainly for a complete machine tool and its cutting conditions.

Acknowledgments

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