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INFLUENCE OF STRUCTURE COMPONENTS ON MACHINE TOOL ACCURACY

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Rezumat. *Pentru mașinile-unelte, precizia părților din structura mașinii-unelte (după prelucrare) ar trebui să facă obiectul unei ameliorări și al îmbătrânirii naturale sau artificiale. Performanța mașinilor cu precizie actuală ca liniaritate sau planeitate a fost mai mare de* 5 μm/m*. Sub această valoare există mari dificultăți. Performanța structurii mașinilor-unelte la fabricarea pieselor structurale ale mașinilor-unelte, cu o acuratețe a planeității, liniaritatea de aproximativ* 2 μm/m*, sunt deviații semnificative formate din semifabricate. Articolul se referă la influența erorilor de formă a pieselor semifinisate și prelucrate asupra lor, asupra formei și în special a ceea ce se întâmplă cu mașinile-unelte de structură atunci când componentele structurii asamblau acest lucru.*

Abstract. *For machine tools, the accuracy of the parts of the machine tool structure (after roughing) should be subject to relief and natural or artificial aging. The performance of the current accuracy of machine tools as linearity or flatness was higher than* 5 μm/m*. Under this value there are great difficulties. The performance of the structure of the machine tools in the manufacture of structural parts of machine tools, with a flatness accuracy that the linearity of about* 2 μm/m*, are significant deviations form of their half-finished. This article deals with the influence of errors of form of semi-finished and machined parts on them, on their shape and especially what happens to structure machine tools when the components of the structure were assembling this.*

Key words: machine tool accuracy, structure components, shape work pieces on machine tools, FEA, FEM, High Precision class.

1. Introduction

For processing parts with small and high-precision deformations, the machine tool must be used in thermostatic enclosures. There are cases when the machine tool is used in a thermostatic chamber located in a thermostatic hall. The need to produce a machine with improved performance with 2-3 classes of higher precision has led to the elaboration of the theoretical foundations of obtaining these performances. On these premises, the guiding finishing machine was refurbished whose performance was of 5 μm/m and it was achieved that the precision of the parts was less than 2 μm/m, respectively on a piece with a length of 4 m, the precision of parallelism and planarity to be covered between 0.005 and 0.008 mm [4].

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When checking the machine tool, it was found that in addition the temperature variation range from the interior of the machine tool was ±3°C to achieve the performance required by the customer. For explanation, the finite element calculation method is applied. The difficulty consists in shaping the component parts of the structure and especially in the loading conditions [5].

2. Theoretical insights

The machining of the structural parts is done by a semi-finished product obtained by casting, forging, welding from cut components from the plates, a.a.

Even if they are subjected to various thermal or other treatments like vibration, aging, etc. Their final form is far from being small. The half-finished part is placed and fixed on the machine table and a first surface called “base” is processed. After that the part is placed and fixed on the “base” surface and the other surfaces are processed, resulting in the desired piece in the end [6].

The same thing goes with the other parts that make up a structure. To achieve the performance shown in the introduction, the work takes into account the deviations of the semi-finished surfaces and the shape of the piece obtained from the semi-finished part. Determining the shape of the piece is done by using the theory of the finite element [1]. Studying the behaviour of the structure is done by studying the assembly of at least two parts of the structure and determining the displacements and stress in the two parts, as well as the deviations of the shape obtained by mounting the structural parts. In the next chapter, the theoretical aspects will be detailed by examples.

3. Applications

3.1 Application 1

Either a piece, with a simple configuration, the component of the structure. The obtained product is represented in Fig. 1. In the case of large pieces in the range of meters the deviations of the shape may be in the range of millimetres and even of centimetres [7].

Traditionally, the semi-finished part (Fig. 1.) [2] is placed on the machine table and the surface A is processed, which becomes the base Aa surface (Fig. 2.). For this, the semi-fabric is supported on the table of the machine on the supporting surfaces and tightly on the surface of the stranger by the application of several tens of thousands or thousands of *N* forces.

Under the action of the tensile forces the lower surface B comes in contact with the surface table. Even if the material flow limit is not exceeded, when the part is released, the Aa surface has form deviations larger than those given by the precision of the machining machine [8].

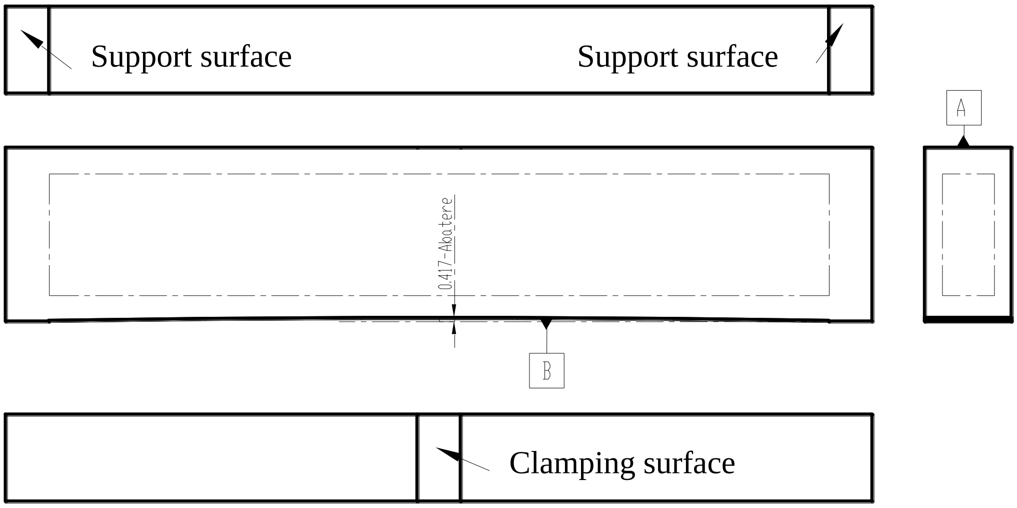

Fig. 1. Half-finished product.

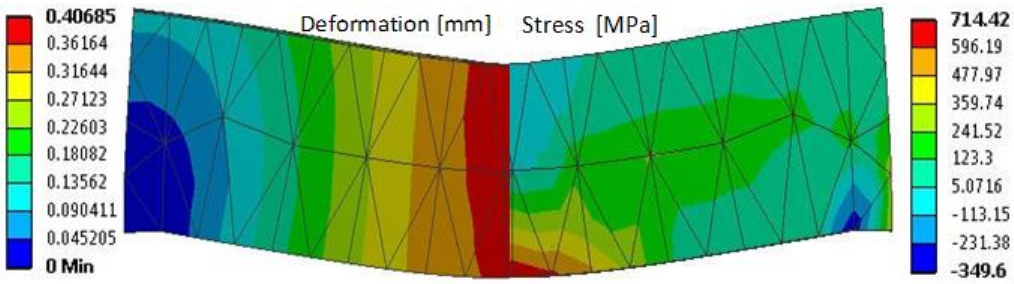

Fig. 2. Half-finished product FEM simulation.

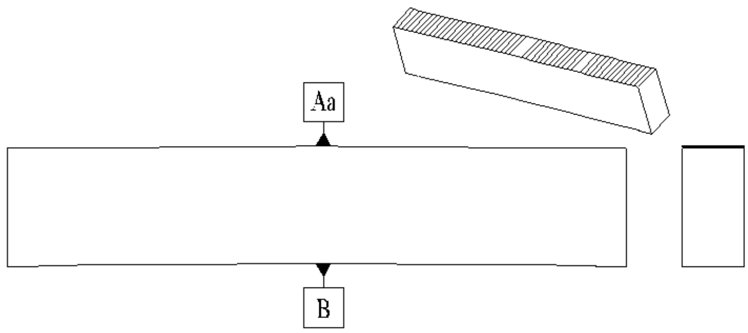

Fig. 3. Half-finished product with the surface Aa machined.

The determination of the Aa surface is made using the theory of the finite element (Fig. 2) applied to the part shown in Fig. 1, which determines the displacements in the surface nodes A. Aa surface elevations are obtained from the A surface coordinates to which the deformation obtained by the finite element (Fig. 2) is added and the processing addition decreases.

The processing of the superficial surface A of the semi-fabric (Fig. 1) leads to the surface Aa of the base of the piece (Fig. 3.-4.) which in free state has the coordinates *X* and *Y* (Table 1).

Table 1. Machining coordinates of the surface Aa

Point	***X***	***Z***	***Point***	***X***	***Z***	***Point***	***X***	***Z***
1	-50	19.10837	19	-17.11539	19.29512	37	18.94231	19.2809
2	-48.17308	19.10727	20	-15.28846	19.30882	38	20.76923	19.26631
3	-46.34615	19.10812	21	-13.46154	19.32199	39	22.59616	19.25142
4	-44.51923	19.11101	22	-11.63461	19.3346	40	24.42308	19.23636
5	-42.69231	19.11582	23	-9.807692	19.3468	41	26.25	19.2213
6	-40.86538	19.12247	24	-7.98077	19.35844	42	28.07692	19.20639
7	-39.03846	19.13083	25	-6.153846	19.36994	43	29.90385	19.1918
8	-37.21154	19.1407	26	-4.326923	19.38217	44	31.73077	19.1777
9	-35.38461	19.15192	27	-2.5	19.39633	45	33.55769	19.16437
10	-33.55769	19.16435	28	2.5	19.39635	46	35.38461	19.15196
11	-31.73077	19.1777	29	4.326923	19.38215	47	37.21154	19.14074
12	-29.90385	19.19175	30	6.153846	19.36989	48	39.03846	19.13086
13	-28.07692	19.20631	31	7.98077	19.35847	49	40.86538	19.12251
14	-26.25	19.22127	32	9.807692	19.34687	50	42.69231	19.11584
15	-24.42308	19.23635	33	11.63461	19.33464	51	44.51923	19.11105
16	-22.59616	19.25139	34	13.46154	19.32199	52	46.34615	19.10818
17	-20.76923	19.26631	35	15.28846	19.30884	53	48.17308	19.10732
18	-18.94231	19.2809	36	17.11539	19.29515	54	50	19.10842

The work surface B of the semi-finished product with surface Aa finished on the machine table according to the drawing scheme of Fig. 4.

Fig. 1. shows the deformation of the surface B before machining.

The surface Bb is determined using the theory of the finite element (Fig. 5.) applied to the part shown in Fig. 4., which determines the displacements in the surface nodes B.

The surface Bb is derived from the B surface quotas to which the deformation obtained by the finite element is added and the processing addition decreases.

Table 2. Machining coordinates of the Bb surface

X	*Coordinate*	*X*	*Coordinate*	*X*	*Coordinate*
-50.000	0.469	-15.000	0.611	20.001	0.608
-47.500	0.490	-12.500	0.611	22.501	0.604
-45.000	0.510	-10.000	0.610	25.001	0.600
-42.500	0.527	-7.500	0.608	27.501	0.594
-40.000	0.542	-5.000	0.605	30.001	0.586
-37.500	0.555	-2.500	0.602	32.501	0.578
-35.001	0.567	-0.000	0.600	35.001	0.568
-32.501	0.577	2.500	0.602	37.500	0.556
-30.001	0.586	5.000	0.605	40.000	0.542
-27.501	0.593	7.500	0.608	42.500	0.527
-25.001	0.599	10.000	0.610	45.000	0.511
-22.501	0.604	12.500	0.611	47.500	0.491
-20.001	0.607	15.000	0.611	50.000	0.470
-17.501	0.609	17.501	0.610		

Finally, the half-finished product will result in the piece shown in Fig. 4.

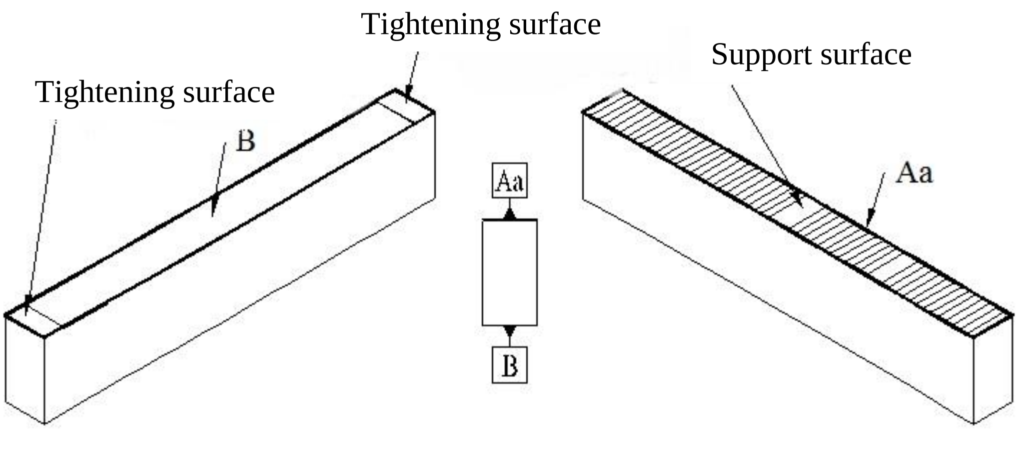

Fig.4 Half-finished product for machining the surface Bb.

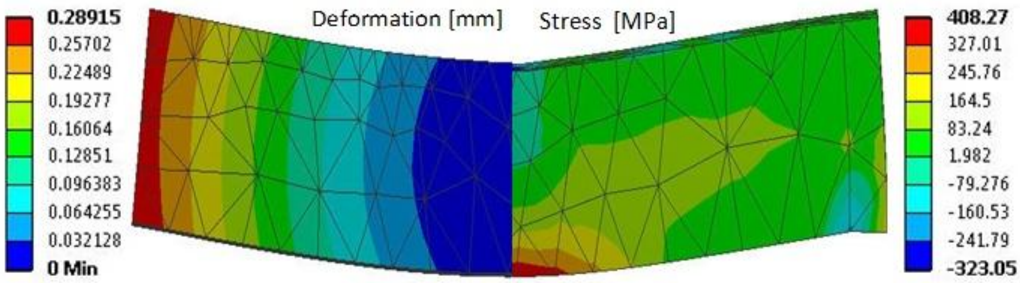

Fig. 5. Half-finished product with machined surface Aa – FEM simulation.

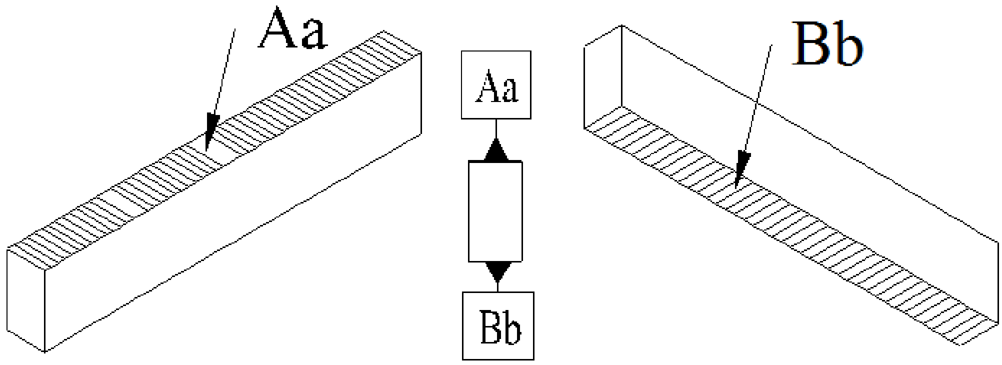

Fig. 6. Part obtained from half-finished product.

The variation in the thickness of the piece (Fig. 4) is shown in Table 3 and partially in Figure 5.

Table 3. Part thickness variation

X	*Thickness*	*X*	*Thickness*	*X*	*Thickness*	*X*	*Thickness*
-50	18.639	-25.0	18.632	2.5	18.795	27.5	18.618
-47.5	18.617	-22.5	18.648	5.0	18.773	30.0	18.605
-45.0	18.599	-20.0	18.665	7.5	18.754	32.5	18.595
-42.5	18.589	-17.5	18.682	10.0	18.736	35.0	18.588
-40.0	18.584	-15.0	18.700	12.5	18.718	37.5	18.584
-37.5	18.583	-10.0	18.735	15.0	18.700	40.0	18.585
-35.0	18.587	-7.5	18.753	17.5	18.683	42.5	18.590
-32.5	18.594	-5.0	18.772	20.0	18.665	45.0	18.6
-30.0	18.605	-2.5	18.794	22.5	18.648	47.5	18.618
-27.5	18.617	0.0	18.796	25.0	18.633	50.0	18.639

The study of the structure is made by the existence of at least two pieces represented in (Fig. 4.) and (Fig. 5.).

In practice, there are various bearing schemes and fastenings for the various parts, but they take into account in particular the configuration of the pieces and not the shape deviations of the part [8].

The paper emphasises the influence of these deviations of the shape on the behaviour of the structure formed by the piece (Fig. 4.) and the plate (Fig. 5.).

Figures 5 and 6 show the support and grip surfaces of the work piece and plate.

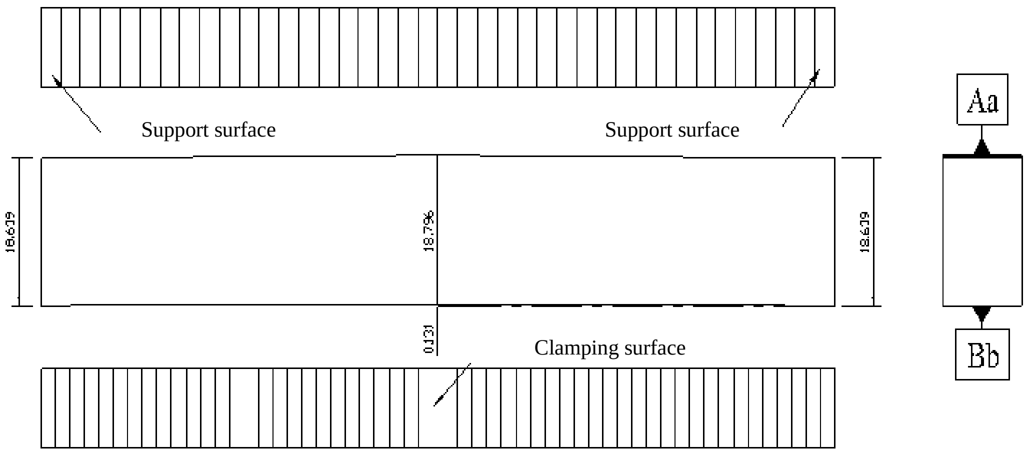

Fig. 5. Piece with clamping and support surfaces with plate.

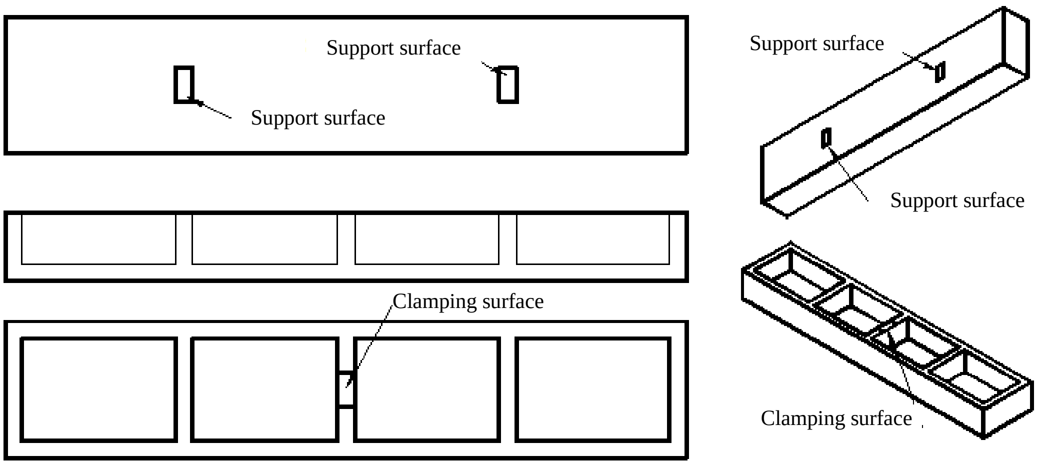

Fig. 6. Plate with clamping and support surfaces.

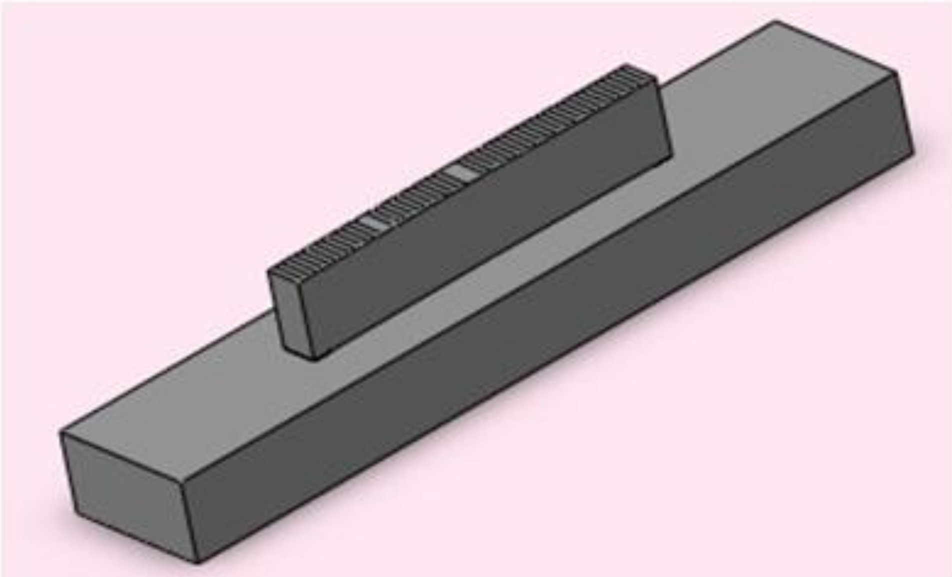

Fig. 7. The structure of the piece (Fig. 5) and the plate (Fig. 6.).

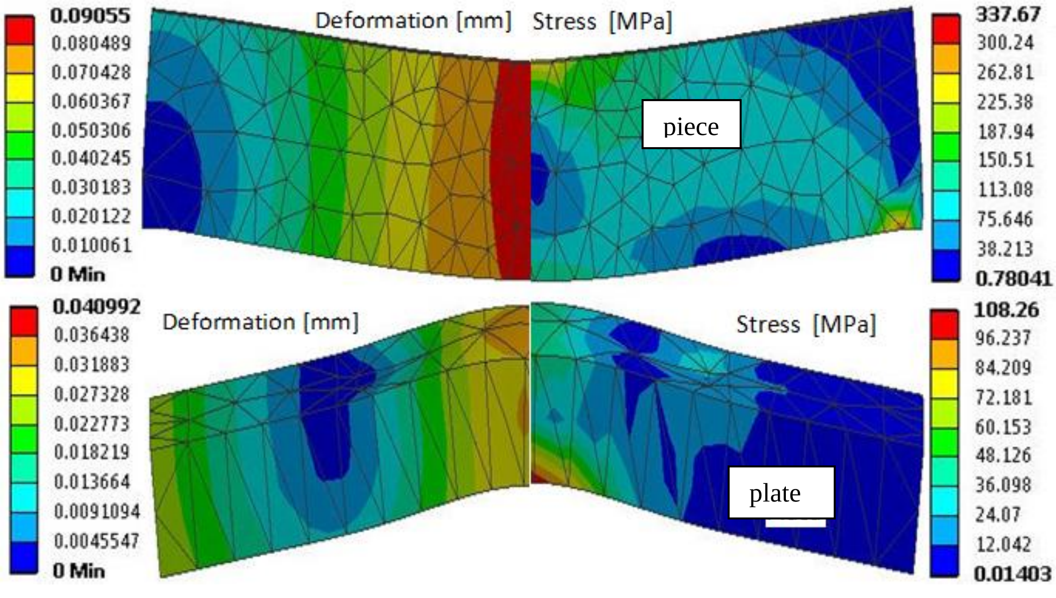

Fig. 8 The piece (Fig. 5) and the plate (Fig. 6) – FEM simulation.

In the structure (Figures 7 and 8) the deviations of the shape of the piece and the plate are analysed.

It is highlighted the deviation from planar surfaces Aa and Bb (Fig. 5) of the respective piece of surfaces A and B of the plate (Fig. 6).

Table 4. Planar deviations of the Aa surface of the piece

X	*Deviation*	*X*	*Deviation*	*X*	*Deviation*	*X*	*Deviation*
-50.000	0.000	-25.337	0.094	2.500	0.229	28.990	0.070
-49.087	0.000	-24.423	0.100	3.414	0.224	29.904	0.064
-48.173	0.001	-23.510	0.106	4.327	0.218	30.817	0.059
-47.260	0.000	-22.596	0.111	5.240	0.213	31.731	0.053
-46.346	0.000	-21.683	0.118	6.154	0.208	32.644	0.048
-45.433	0.001	-20.769	0.123	7.067	0.203	33.558	0.042
-44.519	0.002	-19.856	0.130	7.981	0.198	34.471	0.038
-43.606	0.003	-18.942	0.136	8.894	0.194	35.385	0.033
-42.692	0.006	-18.029	0.141	9.808	0.189	36.298	0.028
-41.779	0.008	-17.115	0.147	10.721	0.184	37.212	0.025
-40.865	0.010	-16.202	0.152	11.635	0.179	38.125	0.021
-39.952	0.014	-15.288	0.158	12.548	0.173	39.038	0.017
-39.038	0.017	-14.375	0.163	13.462	0.168	39.952	0.014
-38.125	0.021	-13.462	0.169	14.375	0.163	40.865	0.011
-37.212	0.025	-12.548	0.173	15.288	0.158	41.779	0.008
-36.298	0.029	-11.635	0.179	16.202	0.152	42.692	0.006
-35.385	0.033	-10.721	0.184	17.115	0.147	43.606	0.003
-34.471	0.038	-9.808	0.189	18.029	0.141	44.519	0.002
-33.558	0.043	-8.894	0.194	18.942	0.135	45.433	0.001
-32.644	0.048	-7.981	0.198	19.856	0.130	46.346	0.000
-31.731	0.054	-7.067	0.203	20.769	0.123	47.260	0.000
-30.817	0.059	-6.154	0.208	21.683	0.118	48.173	0.001
-29.904	0.065	-5.240	0.213	22.596	0.111	49.087	0.000
-28.990	0.070	-4.327	0.218	24.423	0.099	50.000	0.000
-28.077	0.076	-3.414	0.223	26.250	0.087		
-27.163	0.082	-2.500	0.229	27.163	0.082		
-26.250	0.088	0.000	0.228	28.077	0.075		

Table 5. Planar deviations of the Bb surface of the piece

X	*Deviation*	*X*	*Deviation*	*X*	*Deviation*	*X*	*Deviation*
-50.000	0.000	-23.751	0.082	2.500	0.054	28.751	0.080
-48.750	0.011	-22.501	0.082	3.750	0.056	30.001	0.079
-47.500	0.021	-21.251	0.081	5.000	0.058	31.251	0.077
-46.250	0.028	-20.001	0.080	6.250	0.061	32.501	0.076
-45.000	0.036	-18.751	0.079	7.500	0.063	33.751	0.073
-43.750	0.041	-17.501	0.078	8.750	0.065	35.001	0.071
-42.500	0.046	-16.251	0.077	10.000	0.068	36.250	0.068
-41.250	0.051	-15.000	0.075	11.250	0.070	37.500	0.064
-40.000	0.056	-13.750	0.074	12.500	0.072	38.750	0.060
-38.750	0.060	-12.500	0.072	13.750	0.074	40.000	0.056
-37.500	0.064	-11.250	0.070	15.000	0.076	41.250	0.052
-36.250	0.067	-10.000	0.068	16.251	0.077	42.500	0.047
-35.001	0.070	-8.750	0.065	17.501	0.078	43.750	0.041
-33.751	0.073	-7.500	0.063	18.751	0.080	45.000	0.036
-32.501	0.075	-6.250	0.060	20.001	0.081	46.250	0.029
-31.251	0.077	-5.000	0.058	21.251	0.081	47.500	0.022
-30.001	0.079	-3.750	0.056	22.501	0.082	48.750	0.011
-28.751	0.080	-2.500	0.053	23.751	0.082	50.000	0.001
-27.501	0.081	-1.250	0.052	25.001	0.082		
-26.251	0.081	-0.000	0.051	26.251	0.082		
-25.001	0.082	1.250	0.052	27.501	0.081		

Table 6. Planar deviations of the board A surface

X	*Y*	***Deviation***	*X*	*Y*	***Deviation***	*X*	*Y*	***Deviation***	*X*		*Y*	*X*	*Y*	***Deviation***
-100	0	0.006	30	0	0.015	-60	10	0.026	70	10	0.021	-20	20	0.007
-95	0	0.008	35	0	0.019	-55	10	0.028	75	10	0.019	-15	20	0.005
-90	0	0.011	40	0	0.023	-50	10	0.028	80	10	0.016	-10	20	0.003
-85	0	0.014	45	0	0.026	-45	10	0.026	85	10	0.013	-5	20	0.001
-80	0	0.016	50	0	0.029	-40	10	0.023	90	10	0.011	-0	20	0.001
-75	0	0.019	55	0	0.029	-35	10	0.019	100	10	0.006	5	20	0.001
-70	0	0.022	60	0	0.027	-30	10	0.015	-100	15	0.005	10	20	0.003
-65	0	0.024	65	0	0.024	-25	10	0.011	-95	15	0.008	15	20	0.005
-60	0	0.027	70	0	0.022	-20	10	0.008	95	15	0.008	20	20	0.007
-55	0	0.029	75	0	0.019	-15	10	0.005	100	15	0.005	25	20	0.010
-50	0	0.029	80	0	0.016	-10	10	0.002	-100	20	0.004	30	20	0.013
-45	0	0.026	85	0	0.014	-5	10	0.001	-95	20	0.007	35	20	0.016
-40	0	0.023	90	0	0.011	-0	10	-0	-90	20	0.009	40	20	0.019
-35	0	0.019	95	0	0.009	5	10	0.001	-85	20	0.012	45	20	0.021
-30	0	0.015	100	0	0.006	10	10	0.002	-80	20	0.014	50	20	0.022
-25	0	0.011	-100	5	0.006	15	10	0.005	-75	20	0.016	55	20	0.022
-20	0	0.008	-95	5	0.008	20	10	0.008	-70	20	0.018	60	20	0.021
-15	0	0.005	95	5	0.009	25	10	0.012	-65	20	0.020	65	20	0.020
-10	0	0.002	100	5	0.006	30	10	0.015	-60	20	0.021	70	20	0.018
-5	0	0.001	-100	10	0.006	35	10	0.019	-55	20	0.022	75	20	0.016
-0	0	0	-90	10	0.011	40	10	0.023	-50	20	0.022	80	20	0.014
5	0	0.001	-85	10	0.013	45	10	0.026	-45	20	0.021	85	20	0.012
10	0	0.003	-80	10	0.016	50	10	0.028	-40	20	0.019	90	20	0.009
15	0	0.005	-75	10	0.018	55	10	0.028	-35	20	0.016	95	20	0.007
20	0	0.008	-70	10	0.021	60	10	0.026	-30	20	0.013	100	20	0.004
25	0	0.011	-65	10	0.023	65	10	0.024	-25	20	0.010			

Table 7. Planar deviations of plate B surface

X	*Y*	***Deviation***	*X*	*Y*	***Deviation***	*X*	*Y*	***Deviation***	*X*	*Y*	***Deviation***	*X*	*Y*	***Deviation***
-100	0	0.006	30	0	0.015	-60	10	0.026	70	10	0.022	-20	20	0.008
-95	0	0.009	35	0	0.019	-55	10	0.028	75	10	0.019	-15	20	0.005
-90	0	0.012	40	0	0.023	-50	10	0.028	80	10	0.016	-10	20	0.003
-85	0	0.014	45	0	0.027	-45	10	0.026	85	10	0.014	-5	20	0.002
-80	0	0.017	50	0	0.029	-40	10	0.023	90	10	0.011	0	20	0.001
-75	0	0.020	55	0	0.030	-35	10	0.020	100	10	0.006	5	20	0.002
-70	0	0.022	60	0	0.027	-30	10	0.016	-100	15	0.006	10	20	0.003
-65	0	0.025	65	0	0.025	-25	10	0.012	-95	15	0.008	15	20	0.005
-60	0	0.027	70	0	0.022	-20	10	0.009	95	15	0.008	20	20	0.008
-55	0	0.030	75	0	0.020	-15	10	0.005	100	15	0.006	25	20	0.011
-50	0	0.029	80	0	0.017	-10	10	0.003	-100	20	0.005	30	20	0.014
-45	0	0.027	85	0	0.014	-5	10	0.001	-95	20	0.007	35	20	0.017
-40	0	0.023	90	0	0.012	0	10	0	-90	20	0.010	40	20	0.019
-35	0	0.019	95	0	0.009	5	10	0.001	-85	20	0.012	45	20	0.021
-30	0	0.015	100	0	0.006	10	10	0.003	-80	20	0.014	50	20	0.022
-25	0	0.012	-100	5	0.006	15	10	0.005	-75	20	0.017	55	20	0.023
-20	0	0.008	-95	5	0.009	20	10	0.009	-70	20	0.019	60	20	0.022
-15	0	0.005	95	5	0.009	25	10	0.012	-65	20	0.021	65	20	0.021
-10	0	0.003	100	5	0.006	30	10	0.016	-60	20	0.022	70	20	0.019
-5	0	0.001	-100	10	0.006	35	10	0.020	-55	20	0.023	75	20	0.017
0	0	0.001	-90	10	0.011	40	10	0.023	-50	20	0.022	80	20	0.014
5	0	0.001	-85	10	0.014	45	10	0.026	-45	20	0.021	85	20	0.012
10	0	0.003	-80	10	0.017	50	10	0.028	-40	20	0.019	90	20	0.010
15	0	0.005	-75	10	0.019	55	10	0.028	-35	20	0.017	95	20	0.007
20	0	0.008	-70	10	0.022	60	10	0.026	-30	20	0.014	100	20	0.005
25	0	0.012	-65	10	0.024	65	10	0.024	-25	20	0.011			

In the assembly of the plate the following elements are highlighted:

- Variation of piece thickness: 0.179 mm;
- Planar deviation of surface A of the piece: 0.229 mm;
- Planar deviation of surface B of the piece: 0.082 mm;
- Plain deviation of surface A of the board: 0.029 mm;
- Planar deviation of the surface B of the plate: 0.030 mm;
- Deformation of the piece: 0.09055 mm;
- Stress track: 337.67 MPa;
- Plate deformation: 0.040992 mm;
- Stress plate: 100.26 MPa.

3.2 Application 2

Manufacture of a precision machine tool with 2-3 classes that led to the elaboration of the theoretical foundation with which to achieve the desired performance.

This theory was used in the production of a guillotine grinding machine, which was obtained for a 4 m piece of planes, parallelisms and lines of 0.005-0.008 mm [9].

For this, either the part (Fig. 1.). If 84% of the accuracy is determined in the state of impedance, then the deviation of the real shape of 0.417 mm of the lower surface is determined by measurements that it is 0.35 mm.

At the surface processing area A of the part, the same 2 support surfaces and the gripping surface (Fig. 1) are used, with the exception that a 0.35 mm thick pocket is mounted at the middle of the lower surface [10].

The finite element analysis of the part in this case is shown in Figure 9. It is similar to the application 1 the preform with the processed surface A1 (Fig. 10).

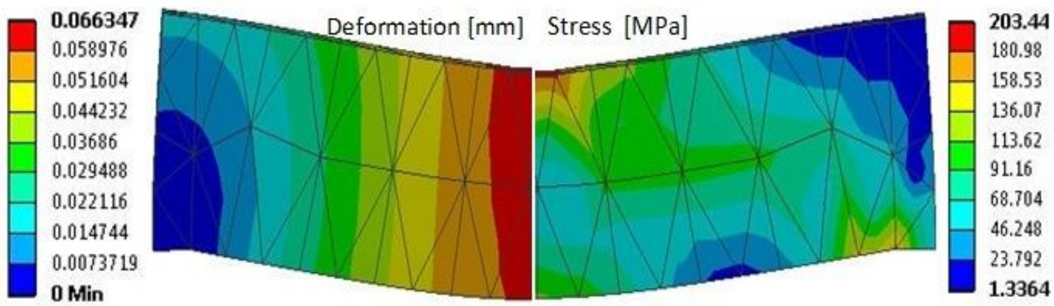

Fig. 9. The semi-finished product– FEM simulation.

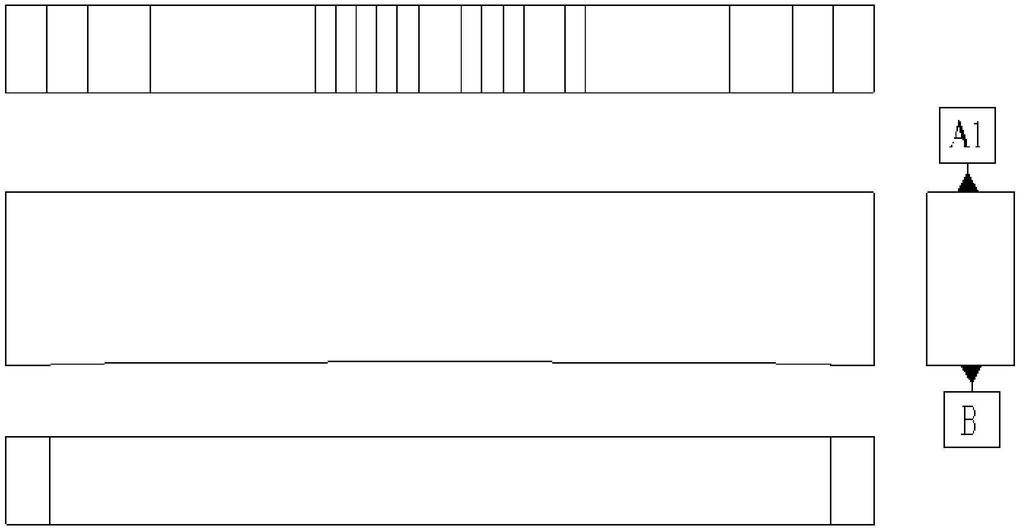

Fig. 10. Semi finished product with processed A1 surface.

Table 8. Machining coordinates of the surface A1

Point	***X***	***Y***	***Point.***	***X***	***Y***	***Point.***	***X***	***Y***
0.000	-50.000	19.983	15.000	-14.375	19.951	29.000	19.125	19.957
1.000	-47.625	19.983	16.000	-12.000	19.949	30.000	21.500	19.960
2.000	-45.250	19.983	17.000	-9.625	19.946	31.000	23.875	19.963
3.000	-42.875	19.982	18.000	-7.250	19.944	32.000	26.250	19.966
4.000	-40.500	19.981	19.000	-4.875	19.941	33.000	28.625	19.969
5.000	-38.125	19.979	20.000	-2.500	19.940	34.000	31.000	19.972
6.000	-35.750	19.977	21.000	0.000	19.938	35.000	33.375	19.975
7.000	-33.375	19.975	22.000	2.500	19.940	36.000	35.750	19.977
8.000	-31.000	19.972	23.000	4.875	19.941	37.000	38.125	19.979
9.000	-28.625	19.969	24.000	7.250	19.944	38.000	40.500	19.981
10.000	-26.250	19.966	25.000	9.625	19.946	39.000	42.875	19.982
11.000	-23.875	19.963	26.000	12.000	19.949	40.000	45.250	19.983
12.000	-21.500	19.960	27.000	14.375	19.952	41.000	47.625	19.983
13.000	-19.125	19.957	28.000	16.750	19.954	42.000	50.000	19.983
14.000	-16.750	19.954						

The determination of the A1 surface is similar to the application 1 using the theory of the finite element applied to the part (Fig. 9), which determines the displacements in the nodes of the surface A.

The surface elevations A1 are obtained from the A surface elevations to which the deformation obtained by the finite element is added (Fig. 9) and the processing addition is decreased. The processing of the superficial surface A of the part (Fig. 9) leads to the surface A1 of the work piece (Figure 10) which in free state has the coordinates X and Y (Table 8.).

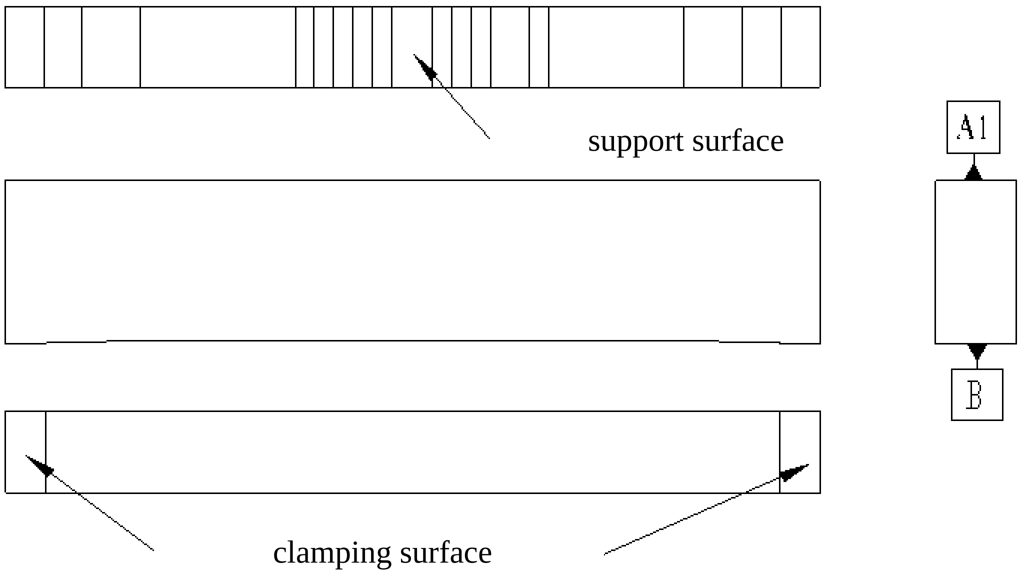

Fig. 11. Semi-finished product with B1 surface machining.

For machining the surface B of the part, it rests on the machine table with the support surface and is tightened by means of the gripping surfaces.

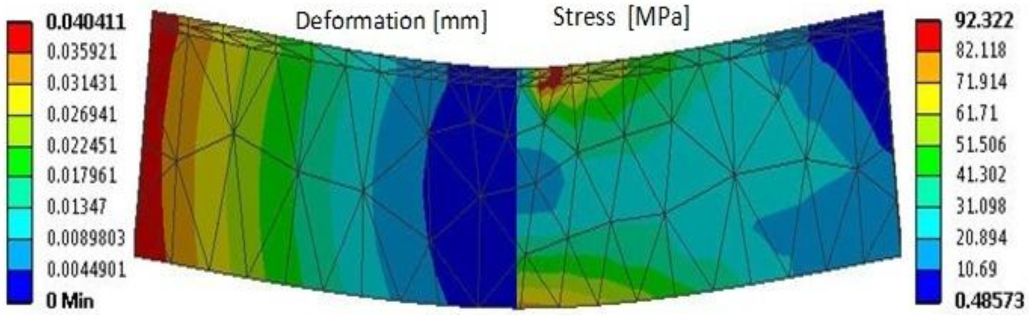

Fig. 12. Semi-finished product – FEM simulation.

The study of the structure (Fig. 11.) made up of the piece (Fig. 11.) and the plate (Fig. 5) is similar to the application 1.

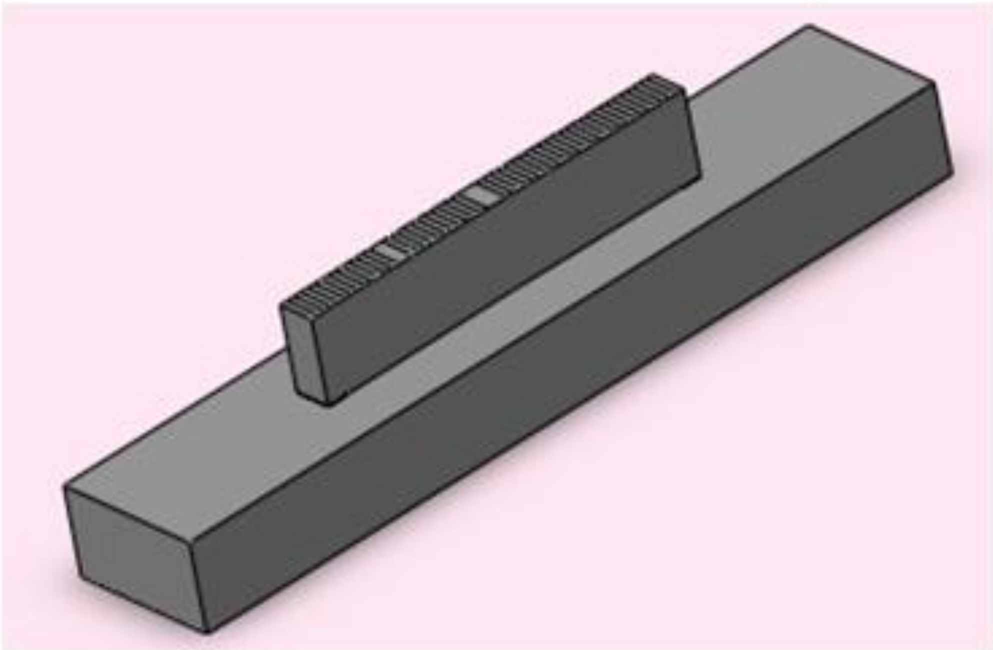

Fig. 13. The structure of the piece (Fig. 11.) and the plate (Fig. 6.).

Figures 14 and 6 show the supporting and gripping surfaces of the work piece and the plate.

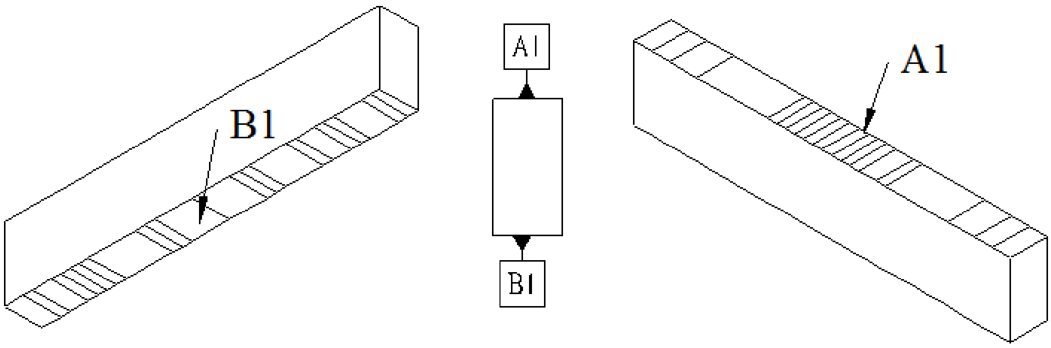

Fig. 14. Part obtained from semi-finished product.

The surface elevations B1 (Table 9.) are made using the theory of the finite element (Fig. 12.) applied to the part (Fig. 11.), which determines the displacements in the nodes of the surface B.

The surface B1 is obtained from the B surface quotas plus the displacements (Fig. 12), then the processing additions are lowered.

Table 9. Machining coordinates of the surface B1

X	***Y***	***X***	***Y***	***X***	***Y***	***X***	***Y***	***X***	***Y***
-50.000	0.642	-27.501	0.618	-7.500	0.604	12.500	0.607	32.501	0.623
-47.500	0.639	-25.001	0.616	-5.000	0.603	15.001	0.608	35.001	0.626
-45.000	0.636	-22.501	0.614	-2.500	0.602	17.501	0.610	37.500	0.628
-42.500	0.634	-20.001	0.612	-0.000	0.601	20.001	0.612	40.000	0.631
-40.000	0.631	-17.501	0.610	2.500	0.602	22.501	0.614	42.500	0.634
-37.500	0.628	-15.001	0.608	5.000	0.603	25.001	0.616	45.000	0.637
-35.001	0.626	-12.500	0.607	7.500	0.604	27.501	0.619	47.500	0.639
-32.501	0.623	-10.000	0.605	10.000	0.605	30.001	0.621	50.000	0.642
-30.001	0.621								

The variation in the thickness of the piece (Fig. 14) is highlighted in Table 10. and partly in Figure 14.

Table 10. Part thickness

X	***Thickness***	*X*	***Thickness***	*X*	***Thickness***	*X*	***Thickness***
-50	19.341	-25.0	19.348	2.5	19.338	27.5	19.349
-47.5	19.344	-22.5	19.347	5.0	19.338	30.0	19.350
-45.0	19.347	-20.0	19.346	7.5	19.340	32.5	19.351
-42.5	19.348	-17.5	19.345	10.0	19.341	35.0	19.350
-40.0	19.350	-15.0	19.344	12.5	19.343	37.5	19.350
-37.5	19.350	-10.0	19.341	15.0	19.345	40.0	19.350
-35.0	19.350	-7.5	19.340	17.5	19.345	42.5	19.348
-32.5	19.351	-5.0	19.338	20.0	19.346	45.0	19.346
-30.0	19.350	-2.5	19.338	22.5	19.347	47.5	19.344
-27.5	19.350	0.0	19.337	25.0	19.348	50.0	19.341

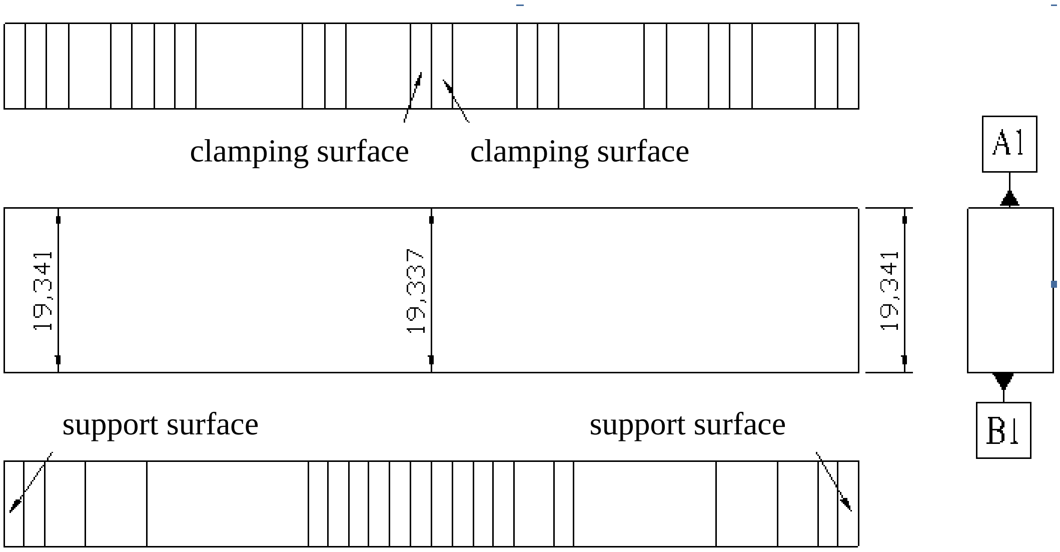

Fig. 15, Part (Fig. 11) and plate (Fig. 6) – FEM simulation method.

In the structure (Figures 13 and 15) the deviations of the shape of the piece and the plate are analyzed. The planar deviation of the surfaces A1 and B1 (Fig. 14.) of the respective parts of the surfaces A and B of the slab (Fig. 6) is highlighted.

Table 11. Plain deviations of the part surface A

X	***Deviation***	*X*	***Deviation***	*X*	***Deviation***	*X*	***Deviation***
-50.000	0.065	-16.750	0.023	1.250	0.001	22.984	0.034
-47.625	0.065	-14.375	0.019	2.500	0.003	25.063	0.037
-45.250	0.065	-13.188	0.017	3.688	0.004	27.141	0.042
-42.875	0.064	-12	0.016	4.875	0.005	29.219	0.046
-40.500	0.062	-10.812	0.013	6.063	0.007	31.297	0.049
-38.719	0.059	-9.625	0.012	7.250	0.009	33.375	0.053
-36.938	0.058	-8.438	0.010	8.438	0.010	35.156	0.056
-35.156	0.056	-7.250	0.009	9.625	0.012	36.938	0.058
-33.375	0.053	-6.063	0.007	12.000	0.016	38.719	0.059
-31.000	0.049	-4.875	0.005	14.375	0.020	40.500	0.062
-28.625	0.044	-3.688	0.004	15.563	0.021	42.875	0.064
-26.250	0.040	-2.500	0.003	16.750	0.023	45.250	0.065
-23.875	0.036	-1.250	0.001	18.828	0.027	47.625	0.065
-21.500	0.031	0.000	0.000	20.906	0.030	50.000	0.065
-19.125	0.027						

Table 12. Plain deviations of the part surface B

X	*Deviation*	*X*	*Deviation*	*X*	*Deviation*	*X*	*Deviation*
-50.000	0.067	-28.751	0.031	0.000	-0.000	30.001	0.033
-48.750	0.066	-27.501	0.029	2.500	0.001	32.501	0.037
-47.500	0.064	-25.418	0.026	5.000	0.002	33.751	0.039
-46.250	0.062	-23.334	0.023	7.500	0.004	35.001	0.042
-45.000	0.059	-21.251	0.020	10.000	0.006	36.250	0.044
-43.750	0.057	-19.168	0.017	11.250	0.007	37.500	0.046
-42.500	0.055	-17.084	0.014	12.500	0.009	39.375	0.049
-40.000	0.050	-15.001	0.011	13.751	0.010	41.250	0.053
-37.500	0.046	-13.751	0.010	15.001	0.011	43.125	0.056
-36.250	0.044	-12.500	0.009	17.501	0.014	45.000	0.060
-35.001	0.042	-11.250	0.007	20.001	0.018	46.250	0.062
-33.751	0.039	-10.000	0.006	22.501	0.021	47.500	0.064
-32.501	0.037	-7.500	0.004	25.001	0.025	48.750	0.066
-31.251	0.035	-5.000	0.002	26.251	0.027	50.000	0.067
-30.001	0.033	-2.500	0.001	27.501	0.030		

Table 13. Plain deviation of the part surface B

X	*Y*	*Deviation*	*X*	*Y*	*Deviation*	*X*	*Y*	*Deviation*	*X*	*Y*	*Deviation*
-100	0	0.002	80	0	0.006	24	10	0.004	-40.75	20	0.007
-95	0	0.003	85	0	0.005	29	10	0.005	-36.5	20	0.006
-90	0	0.004	90	0	0.004	33.25	10	0.006	-32.25	20	0.005
-85	0	0.005	95	0	0.003	38.25	10	0.008	-28	20	0.004
-80	0	0.006	100	0	0.002	42.5	10	0.009	-23.75	20	0.003
-75	0	0.007	-100	5	0.002	47.5	10	0.010	-19.5	20	0.002
-70	0	0.008	-95	5	0.003	50	10	0.010	-15.25	20	0.002
-65	0	0.009	95	5	0.003	54.5	10	0.010	-11	20	0.001
-60	0	0.010	100	5	0.002	59.5	10	0.009	-6.75	20	0.001
-55	0	0.011	-100	10	0.002	64	10	0.009	-2.5	20	0
-50	0	0.010	-92.5	10	0.003	69	10	0.008	0	20	0
-45	0	0.010	-88	10	0.004	73.5	10	0.007	2.5	20	0

-40	0	0.008	-83	10	0.005	78.5	10	0.006	6.75	20	0.001
-35	0	0.007	-78.5	10	0.006	83	10	0.005	11	20	0.001
-30	0	0.005	-73.5	10	0.007	88	10	0.004	15.25	20	0.002
-25	0	0.004	-69	10	0.008	92.5	10	0.003	19.5	20	0.002
-20	0	0.003	-64	10	0.009	100	10	0.002	23.75	20	0.003
-15	0	0.002	-59.5	10	0.009	-100	15	0.002	28	20	0.004
-10	0	0.001	-54.5	10	0.010	-97.5	15	0.002	32.25	20	0.005
-5	0	0	-50	10	0.010	97.5	15	0.002	36.5	20	0.006
-0	0	0	-47.5	10	0.010	100	15	0.002	40.75	20	0.007
5	0	0	-42.5	10	0.009	-100	20	0.001	45	20	0.008
10	0	0.001	-38.25	10	0.008	-97.5	20	0.002	47.5	20	0.008
15	0	0.002	-33.25	10	0.006	-95	20	0.002	50	20	0.008
20	0	0.003	-29	10	0.005	-90.5	20	0.003	54.5	20	0.008
25	0	0.004	-24	10	0.004	-86	20	0.004	59	20	0.008
30	0	0.005	-19.75	10	0.003	-81.5	20	0.005	63.5	20	0.007
35	0	0.007	-15.5	10	0.002	-77	20	0.005	68	20	0.007
40	0	0.008	-10.5	10	0.001	-72.5	20	0.006	72.5	20	0.006
45	0	0.009	-6.25	10	0	-68	20	0.007	77	20	0.006
50	0	0.010	-1.25	10	-0	-63.5	20	0.007	81.5	20	0.005
55	0	0.011	1.25	10	-0	-59	20	0.008	86	20	0.004
60	0	0.010	6.25	10	0	-54.5	20	0.008	90.5	20	0.003
65	0	0.009	10.5	10	0.001	-50	20	0.008	95	20	0.002
70	0	0.008	15.5	10	0.002	-47.5	20	0.008	97.5	20	0.002
75	0	0.007	19.75	10	0.003	-45	20	0.008	100	20	0.001

Table 14. Plain deviation of the part surface

X	***Y***	***Deviation***	***X***	***Y***	***Deviation***	***X***	***Y***	***Deviation***	***X***	***Y***	***Deviation***
-100	0	0.003	60	0	0.010	29	10	0.006	-32.25	20	0.006
-95	0	0.004	70	0	0.008	33.25	10	0.007	-28	20	0.005
-90	0	0.005	80	0	0.007	38.25	10	0.008	-23.75	20	0.004
-80	0	0.007	90	0	0.005	42.5	10	0.009	-19.5	20	0.003
-70	0	0.008	100	0	0.003	47.5	10	0.010	-15.25	20	0.002

-60	0	0.010	-100	5	0.003	50	10	0.011	-11	20	0.002
-50	0	0.011	100	5	0.003	59.5	10	0.010	-6.75	20	0.001
-40	0	0.009	-95	5	0.004	64	10	0.009	-2.5	20	0.001
-30	0	0.006	95	5	0.004	69	10	0.008	0	20	0.001
-5	0	0.001	-92.5	10	0.004	73.5	10	0.008	2.5	20	0.001
5	0	0.001	-88	10	0.005	78.5	10	0.007	6.75	20	0.001
-15	0	0.002	-83	10	0.006	83	10	0.006	11	20	0.002
15	0	0.002	-78.5	10	0.007	88	10	0.005	15.25	20	0.002
95	0	0.004	-73.5	10	0.008	92.5	10	0.004	19.5	20	0.003
-85	0	0.006	-69	10	0.008	-100	10.	0.003	23.75	20	0.004
-25	0	0.005	-64	10	0.009	100	10.	0.003	28	20	0.005
25	0	0.005	-59.5	10	0.010	-97.5	15	0.003	32.25	20	0.006
85	0	0.006	-54.5	10	0.011	97.5	15	0.003	36.50	20	0.007
-75	0	0.008	-50	10	0.011	-100	15.	0.002	40.75	20	0.008
-35	0	0.007	-47.5	10	0.010	100	15.	0.002	45	20	0.008
35	0	0.007	-42.5	10	0.009	-97.5	20	0.003	47.5	20	0.008
75	0	0.007	-38.25	10	0.008	-95	20	0.003	50	20	0.009
-65	0	0.009	-33.25	10	0.007	-90.5	20	0.004	54.5	20	0.009
65	0	0.009	-29	10	0.006	-86	20	0.005	59	20	0.008
-45	0	0.010	-24	10	0.004	-81.5	20	0.005	63.5	20	0.008
45	0	0.010	-19.75	10	0.003	-77	20	0.006	68	20	0.007
-55	0	0.011	-15.5	10	0.002	-72.5	20	0.007	72.5	20	0.007
55	0	0.011	-10.5	10	0.001	-68	20	0.007	77	20	0.006
-20	0	0.003	-6.25	10	0.001	-63.5	20	0.008	81.5	20	0.005
-10	0	0.001	-1.25	10	0	-59	20	0.008	86	20	0.005
0	0	0.001	1.25	10	0	-54.5	20	0.009	90.5	20	0.004
10	0	0.001	6.25	10	0.001	-50	20	0.009	95	20	0.003
20	0	0.003	10.5	10	0.001	-47.5	20	0.008	97.5	20	0.003
30	0	0.006	15.5	10	0.002	-45	20	0.008	-100	20.	0.002
40	0	0.009	19.75	10	0.003	-40.75	20	0.008	100	20.	0.002
50	0	0.011	24	10	0.004	-36.5	20	0.007			

Conclusions

1. This paper records for the first time the positioning of the parts to the machining and the precision of the structure made from the machined parts.
2. The precision of a structure is determined by the execution precision of the component parts.
3. The precision of the components is determined largely by their primary form, namely the way of making, casting, forging, welding, etc.
4. The way of making a structure with a special behaviour as precision was experimented in the eighth decade on the guiding grinding machine where the precision improved by 3 classes.
5. In achieving the structure of this machine, the need for aging treatment of the components was eliminated, by correctly placing the processing of at least two surfaces.
6. The theoretical explanation is presented in the paper by 2 applications that use the finite element theory combined with geometrical elements that cause the shape of the piece to change.
7. The difficulty in mathematical modelling is how to use the theory of the finite element with the combination of geometry when changing the shape of the piece.
8. In application 1 and 2 there is presented the processing of two opposing surfaces of the piece and its influence on the assembly in the same pair as in application 1.
9. In application 2, the initial shape of the piece is taken into account and a work piece is installed to prevent excessive deformation of the work piece on the machine table for first machining (surface A).
10. The processing described in application 2 improves the following performance against application 1:
11. The thickness of the piece is reduced by 95%;
12. The planar deviation of the surface A of the piece is reduced by 72%;
13. The planar deviation of the surface B of the piece is reduced by 18%;
14. The planar deviation of the surface A of the board is reduced by 62%;
15. The planar deviation of the surface B of the board is reduced by 63%;
16. The deformation of the work piece is reduced by 61%;
17. The stress of the piece is reduced by 66%;

18. Plaque deformation is reduced by 63%;
19. Plaque stress is reduced by 63%.
20. The paper opens the perspective of making parts with very small deviations, such as the measuring track kit, components of optical devices, etc.
21. A special mention can be made of the finishing of the telescope’s mirror. If the methodology presented in the paper had been known, it would have avoided the deformation of the Ojinzi when it was sent into space.
22. The paper opens the perspectives of treating other applications such as temperature influence on deformations and stress and precision on the machine tool.

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