A revolution in the application of flange joints?

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1. Up-to-date state

In the application of common flange joints there is a tightening strength provided by means of bolts. An additional flexural load of flanges is a disadvantage at the provision of tightening strength, which is needed for a joint tightness.

2. The basic requirements for development of the new joint.

During a development of the new joint we considered the requirement for a removing of additional flexural load in flanges by which means there was a decreasing of joint weight. We applied a flexible sealing with small deformation as a flange joint tightening to provide joint tightness without any claim for a tightening strength initiation. A tightening effect is provided a medium pressure on the flexible sealing. Another requirement is to enable an adjustment with two degrees of freedom during an assembly or during an operation.

3. The result of development

As a result of development is a functional design of the flange joint DN50 illustrated in Fig. 1.

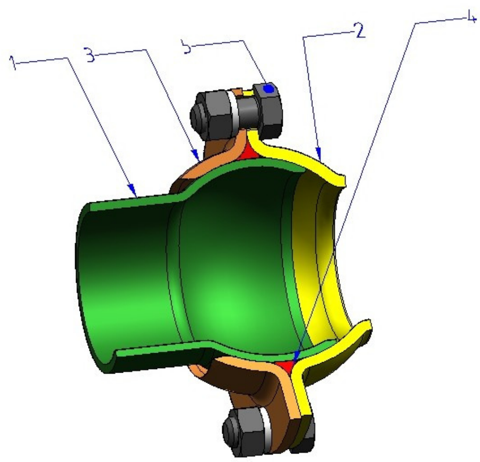

Fig.1 Flange joint DN50

It is supposed that there is a development of the whole series for type of flange joints with an inner diameter DN25 – DN150 (the implied dimensions of individual inner diameter are available on web page www.lignotech.sk).
A joint itself consist of a socket 1 at the end spherically surfaced, a neck 2 (i.e. input neck) flanged and spherically surfaced, a neck 3 (i.e. output neck) flanged and spherically surfaced, a flexible sealing 4 and a bolted connection 5.
The centres of spherical surfaces of the socket 1, the necks 2 and 3 are identical and posed in the axis of a socket pipe 1. A described arrangement enables a rotating of the socket 1 towards the neck 2 and 3.
A flange of the neck 2 and a flange of the neck 3 are jointed with the bolted connection 5. The flange of the neck 2 and the flange of the neck 3 touch down at each other and there is no additional flexural load of the flanges.
An area between the spherical surface of the socket 1 and the transition radius of the flanges for necks 2 and 3, is filled with the flexible sealing 4. During a bolt fastening of the flanges of the neck 2 and 3 there is the flexible sealing compressed and so the joint tightness is reached. During a pressure increasing there is the tightening effect reached by a compression of the sealing 4 and so its tightness is provided.

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The sealing itself has got a special shape providing a tightness of defined space for the tightening between the spherical surfaces of the socket 1 and the transition radius of the flanges for necks 2 and 3.
The socket 1 and the necks 2 and 3 are cold-pressed-made. A patent protection of the new flange joint is provided together with the development.

4. Advantages of the new flange joint compared with common flange joints.

4.1. Weight decreasing of flange joint

The described realisation of the flange joint enables the great weight decreasing of the joint. Thereinafter there will be documented the actual results achieved in the case of functional model DN50 and flange joint DN125. These designs were documented on the base of analysis for a stress state by the finite element method and their comparison with common flange joints corresponding to the dimensional standard of metal pipeline flanges ISO 2084-1974 (DIN 2501). Establishing the comparable conditions we apply the flange joint with defined length 90 mm for the joint DN50. The comparison is evident in following Table 1.

Tab.1 Comparison of the flange joints with inner diameter DN50

Joint type	Operational pressure [MPa]	Testing pressure [MPa]	Flange dimension [mm]	Joint weight [kg]	Bolted joint
New joint DP10	1	2	Ø 122-4	0.97	4xM10
New joint DP25	2.5	5	Ø 122-4	0.97	6xM10
New joint DP40	4	8	Ø 122-4	0.97	8xM10
ISO DP06	0.6		Ø140/ Ø60-12	2.78	4xM12
ISO DP40	4		Ø165/ Ø60-16	4.44	4xM16

Expected values of specified pressure and a testing pressure were for a functional design DN50 verified with a pressure test. The 4-bolts-joint was loaded repeatedly with the testing pressure 5 MPa and the 8-bolts-joint was loaded repeatedly with the testing pressure 10 MPa.

Establishing the comparable conditions we apply the flange joint with defined length 130 mm for the joint DN125. In Table 2 there is the comparison.

Tab.2 Comparison of the flange joints with inner diameter DN 125

Joint type	Operational pressure [MPa]	Testing pressure [MPa]	Flange dimension [mm]	Joint weight [kg]	Bolted joint
New joint DP10	1	2	Ø 208-5,5	4.356	4xM16
New joint DP40	2.5	5	Ø 208-5,5	4.356	8xM16
ISO DP06	0.6		Ø240/ Ø130-16	9.818	4xM16
ISO DP16	1.6		Ø250/ Ø130-18	11.84	8xM16
ISO DP40	4		Ø270/ Ø120-20	15.49	8xM24

4.2. Two degrees of freedom during assembly.

It is possible to rotate the socket 1, which is welded with the pipeline, in two directions what enables to make easy an adjustment during the assembly. A change position of the socket 1 towards the neck 2 and the neck 3 is possible as well as during an operation with a keeping to the joint tightness.
The joint itself acts like a knuckle-joint whereby it eliminates a potential additional stress consequent from a potential movement in pipelines.
Considering to a joint flexibility there is the joint suitable especially for an area with increased seismicity.
It can be important an application in flexible systems with larger deformations, for example in pipe distribution systems of ships.

4.3. Simplification of armature castings and their weight decreasing.

A very interesting field for application of the new flange joint is a field of armatures. By application of the socket 1, the neck 3 and the sealing 4 in flange armatures there are 4 flanges practically eliminated. In the castings of armature bodies there are occurred the considerable simplification and weight decreasing.
An application of the flange joint in armatures is illustrated in Fig. 3. It is displayed the possibility of direct assembly for sockets 1 into an armature body as well as a solution design of the application of the flange joint with two degrees of freedom in the case that it is required to replace an armature without pipeline disassembly.

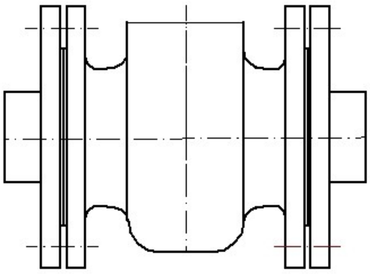

Fig.2 Common flange joint of an armature and a pipeline

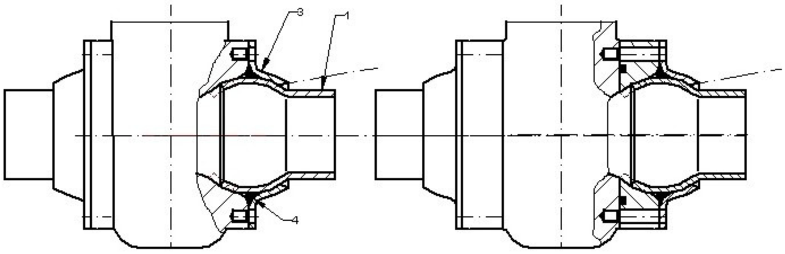

Fig.3 Solution alternatives of a armature connecting by means of the new flange joint

4.4. Significant increasing of operational pressure

The new flange joint with two degrees of freedom enables a considerable increasing of operational pressures. In following part there is documented the state of stress analysis for individual segment of the new flange joint by means of the finite element method.
An analysis is done for the functional design of the flange joint DN50 with application of 4 and 8 bolts. Then the analysis is compared with the findings of pressure test for the functional design. The analysis is also extended for an anticipated flange joint DN125 with an application of 4 and 8 bolts because in this way it is possible to examine the described problem more comprehensively.

5. Stress analysis of flange joint

The stress state analysis of a designed flange joint was performed for all dimensional sizes, with a nominal diameter from DN25 to DN125, in the realisations with four, six and with eight bolts in a flange joint. An aim of analyses was to determine limit values of an operational pressure with regard to a limit bearing capacity of individual components of armature. The analyses were performed with the finite element methods in the program COSMOS DesignStar, ver. 2008 (Desault systemes).
In following text there are some results of analyses presented for the inner diameters DN50 and DN125 in the realisations with four and with eight bolts in the flange joint.

5.1 Computing models

Computing models were built on the base of the complex 3D models of flange joints designed in the program Solid Edge ver.20 (UGS PLM Software). These models were adapted for needs of analysis like the quarter symmetric models. The bolt joints were modelled by means of the model tools accessible in the used program (so called „bolts“). Ten-nodes body element of type TETRA10 were used for a grid creation of finite elements, In Fig. 1 and Fig. 2 there are presented 3D symmetric

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models of the flange joints with a diameter DN50. In Fig.3 and Fig.4 there are illustrated the grid of finite element for 4-bolts and 8-bolts design. The models for diameter DN125 were analogical to corresponding dimensional parameters.

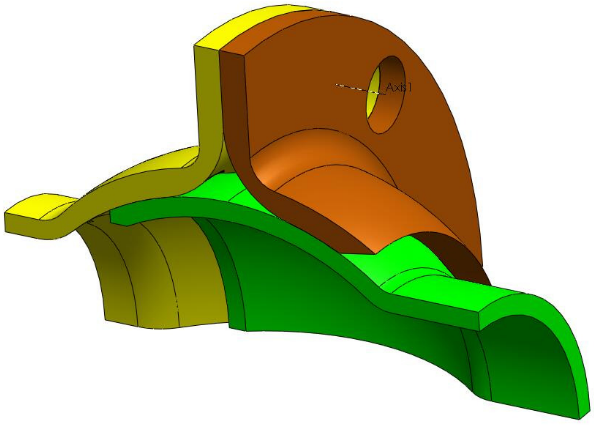

Fig. 1. 3D symmetric model of the joint DN50 – 4 bolts

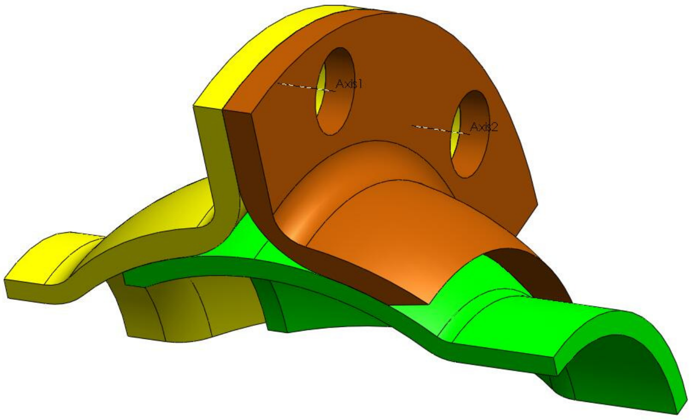

Fig. 2. 3D symmetric model of the joint DN50 – 8 bolts

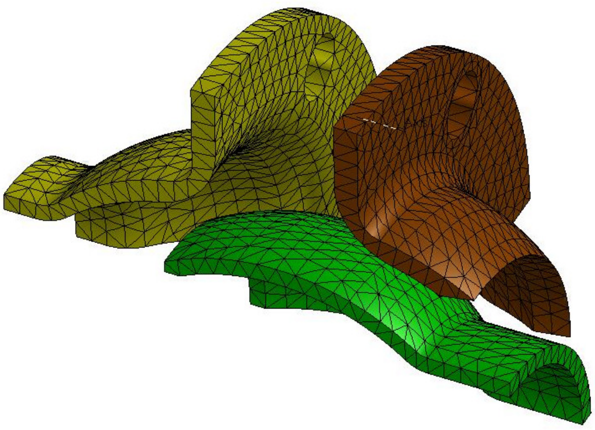

Fig. 3. Mesh model of finite elements for the joint DN50 – 4 bolts

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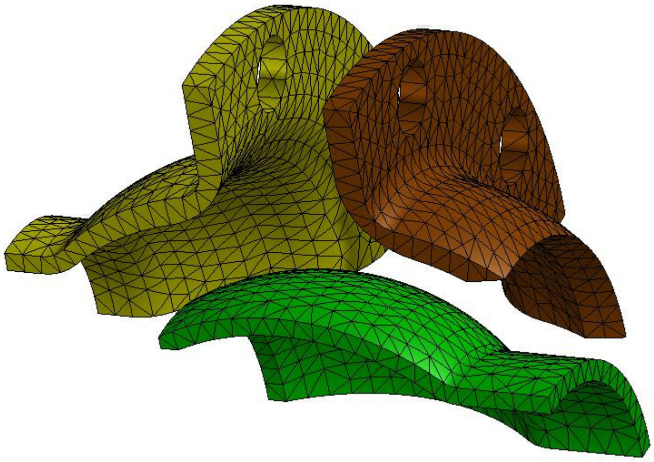

Fig. 4. Mesh model of finite elements for the joint DN50 – 8 bolts

Boundary conditions i.e. the relations and loading of internal overpressure, which are illustrated in Fig. 5 and Fig. 6, are identical for both size diameters and both realisations of bolt joints.

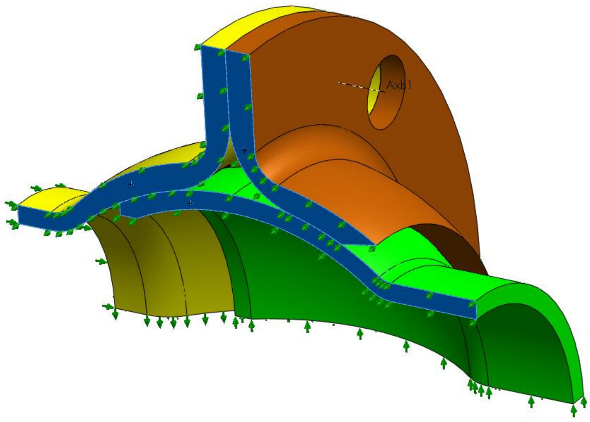

Fig. 5. Relation representation on the limits of symmetry and in an axial direction of the flange joint

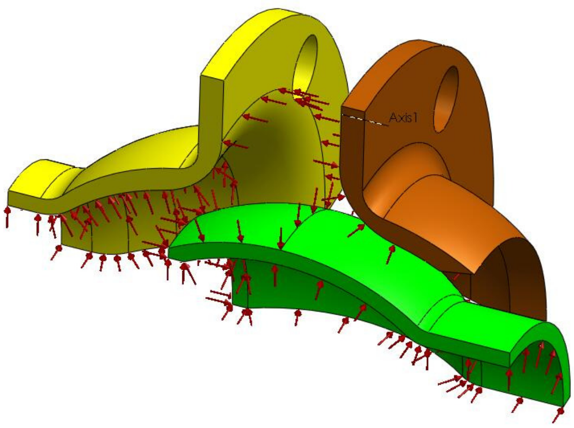

Fig. 6. Representation of model loading with internal overpressure

In Table 3 there are physical and mechanical characteristics of material for armature elements. The physical and mechanical characteristics of steel Kohal 240 are for a deep-drawing steel with the mark identification Kohal 240 (product of US Steel Inc. Košice, Slovakia). In a calculation there was applied

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“plastic-bilinear von Mises material model”. For simulated bolt joint there was considered “ideal elastic material model” because the used program product does not enable an application of different material model.

Tab.3. Physical and mechanical characteristics of steel Kohal 240

Characteristics	Value
Elastic modulus [MPa]	200 000
Poisson's ratio	0.29
Mass density [kg/m^3]	7900
Yield strength [MPa]	280
Ultimate strength [MPa]	330

5.2 Realisation of the analysis and the result processing

An analysis was being performed by a linear static calculation with a gradually increasing pressure according to time curves illustrated in Fig. 7. Graph and with the using of above-mentioned material models developed for individual parts of armature.

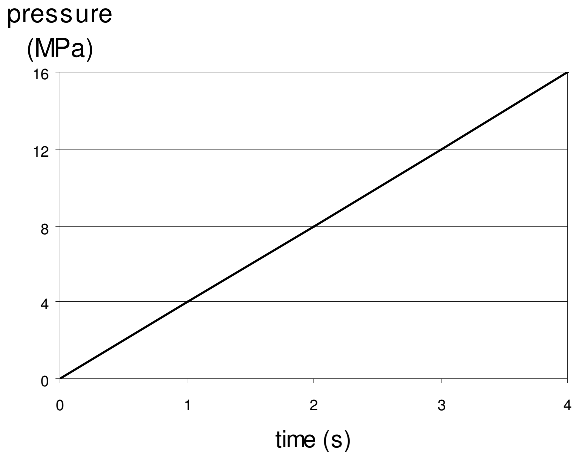

Fig. 7. Graph with curve of time and pressure loading

The results of calculation were processed like the envelopes of the highest comparative stresses - σ_{eff} on individual parts of armature according to von Mises’ strength theory.
In following figures there are the illustrative sketches of stress behaviour and the graphs for dependence of stress on loading.

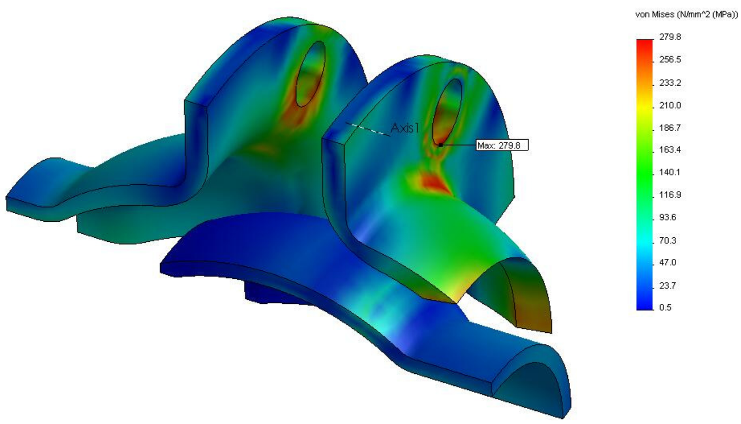

Fig. 8. Stress behaviour σ_{eff} at the pressure 4 MPa, armature DN50 – 4 bolts

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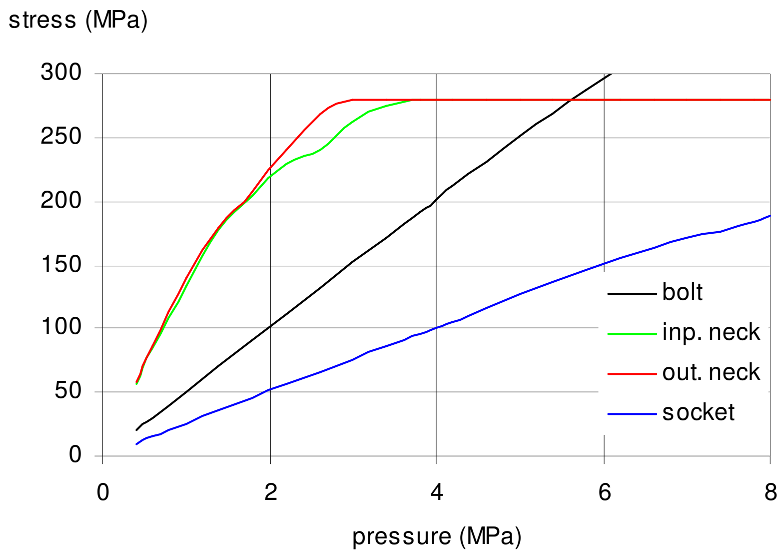

Fig. 9. Dependence of the component stress on the loading, armature DN50 – 4 bolts

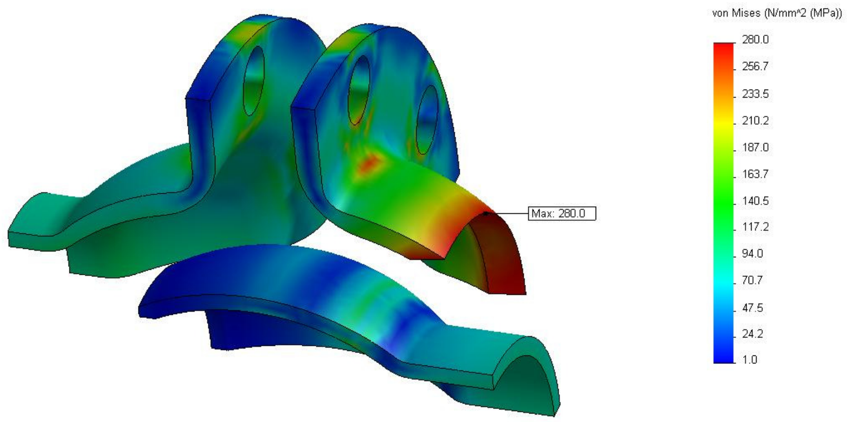

Fig. 10. Stress behaviour σ_{eff} at the pressure 8 MPa, armature DN50 – 8 bolts

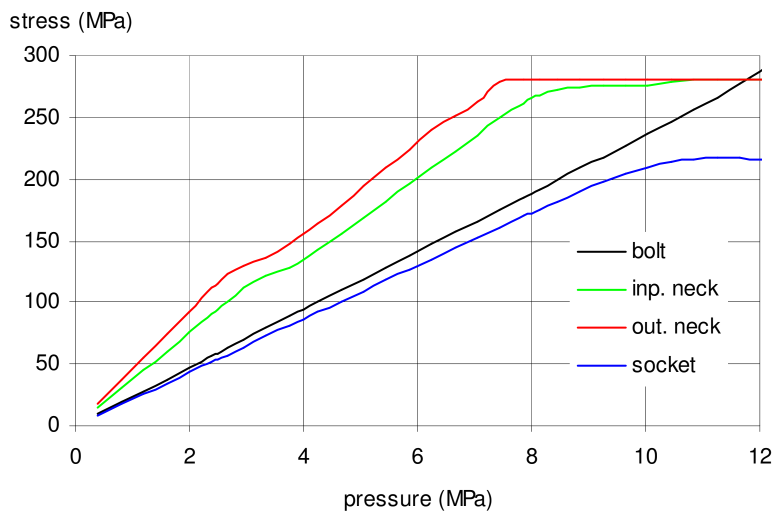

Fig. 11. Dependence of the component stress on the loading, armature DN50 – 8 bolts

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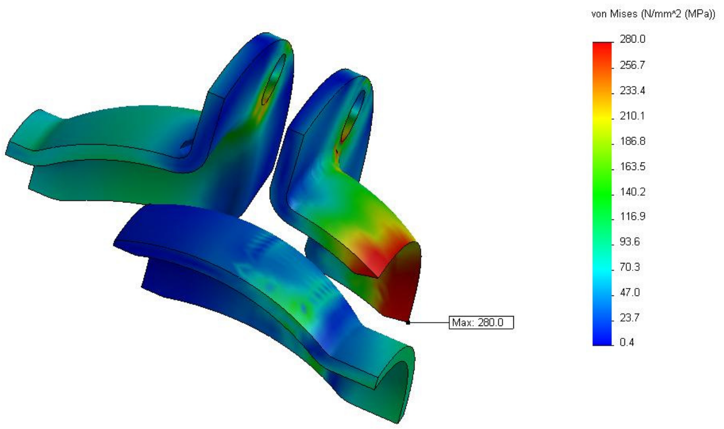

Fig. 12. Stress behaviour σ_{eff} at the pressure 6 MPa, armature DN125 – 4 bolts

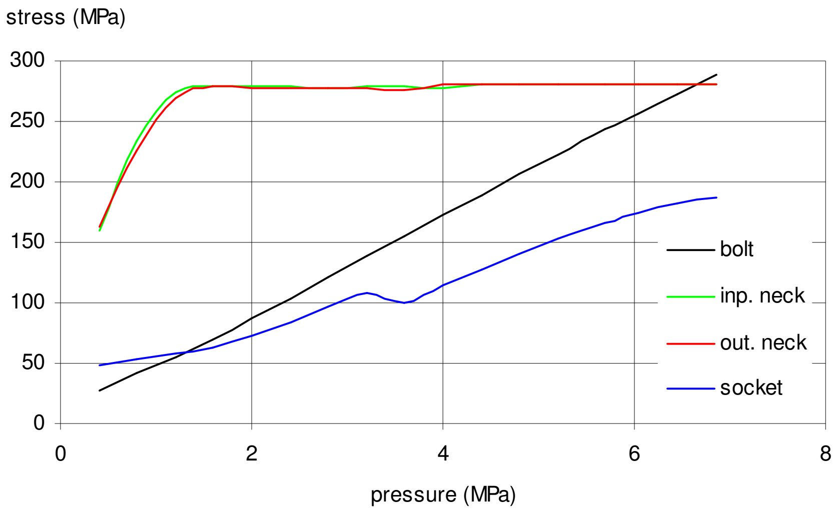

Fig. 13. Dependence of the component stress on the loading, armature DN125 – 4 bolts

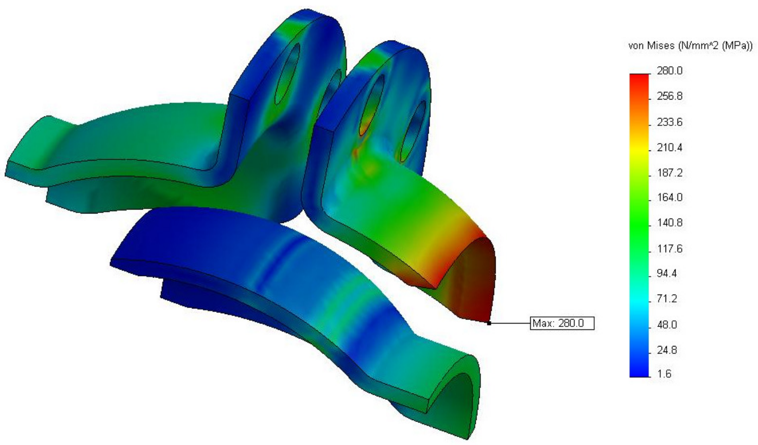

Fig. 14. Stress behaviour σ_{eff} at the pressure 8 MPa, armature DN125 – 8 bolts

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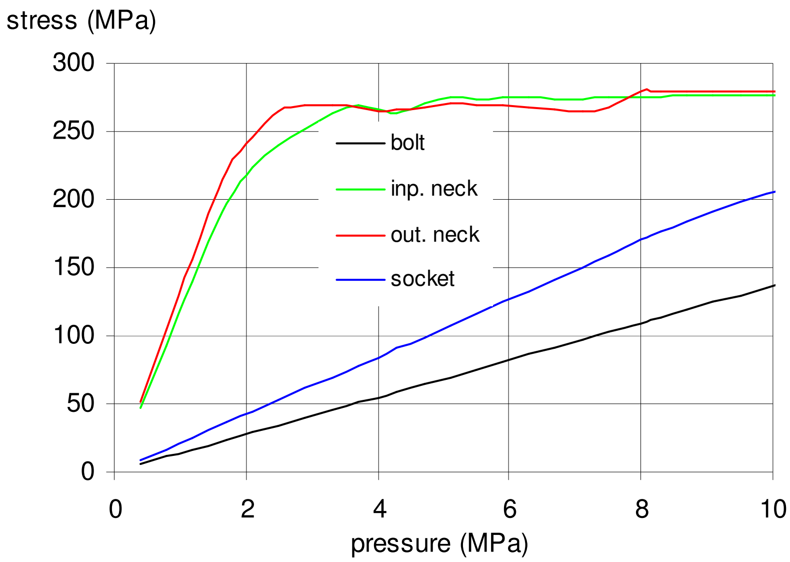

Fig. 15. Dependence of the component stress on the loading, armature DN125 – 8 bolts

6. Conclusion.

We can state from the description, analyses and tests of functional design that the new flange joints with two degrees of freedom compared with common flange joints:

- represents the weight decreasing of the flange joint from 40 to 75%,
- enables two degrees of freedom during the assembly and during the operation,
- finds the considerable application predominantly in the flange armatures,
- is this joint suitable especially for the areas with increased seismicity,
- obtains the application in flexible systems with larger deformations, for example in the pipe distribution systems of ships.

The performed computing analyses enable to define the limit values of allowable loading with the operating pressure in pipelines in dependence on the inner diameter of the flange joint and in dependence on the number of bolts.

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