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THE TEMPERATURE - AND STRESS FIELDS OF VALVES OF IC ENGINE

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Abstract

The paper concerns building up one exhaust valve of composite-steel and two intake ceramics-steel valves of a hypothetical adiabatic engine. The input temperatures were computed using three diverse FORTRAN95 programs, solving a shortened optical integral equation with radiative transfer, transient differential equation while starting and switching off the engine and a rod like diff. Equation with 'progonka' (Thomas) solution. The ANSYS11 programme was fed up with the output of the programs. It turns out that, generally, a mineralogical, crystal-chemical approach to the joining of materials results in stresses known from the common metal engines. Such problems as CTE enhancing (partly hypothetical) by means of doping the anionic compounds by cationic ones, swelling of structures, compressibility versus coefficient of thermal expansion (CTE) , compatibility of crystal motifs while joining, thermal shock resistance, switching the bonds, mechanical longevity, radiation protection etc were addressed. It turns out that true nature of the temperature and stress field, especially of the exhaust valve is closer to the FORTRAN temperature computation than, e.g. from the heat film coefficients (ANSYS11).

Keywords: *intake valve, output valve, YSZ, ferberite, scheelite, silicides, pyroxene, composite, joining of materials, thermal conductivity, radiative transfer, thermal expansion*

1. Introduction

Owing to the objective causes, also shortage of place, only three of seven models of the valves will be presented here, and also a few of a bunch of pictures and files. Almost all the data are temperature dependent and the unknown ones - computed, e.g. Young modulus from isomorphic crystal structures, absorption and emissivity or reflectivity from optics or electrical resistance; the unknown thermal conductivity from, e.g. an appraisal of exponent in the conductivity-wave velocity equation etc. The immense heap of data will not be presented, either; nor the literature thereof (upon request). Also, briefly, the computing procedure was as follows. The temperature drops at definite layers of ceramics were computed using a shortened optical integral equation which takes into account the radiative transfer. In case of metals, composites and definite silicides – a transient differential equation was used while starting and switching off the engine and the temperature of the 'second' wall estimated. Also, unitary heat flow methods were used. Finally, to estimate the temperature of the pin of the valves, the rod-like differential equation with 'progonka' (Thomas) solution was used to consecutively diverse milieu: hot or cold gases of the channel, along the pin-liner and to the protruding part of the pin beneath the engine hood. Also stick-temperatures estimated. All the equations were computed according to the Junior author's FORTRAN95 programmes. To estimate or map the temperatures and stresses of the valves, the ANSYS 11was fed up with the output of the FORTRAN95 programmes. The methodology of assuming temperature was somewhat in harmony of [Kwasniowski et al.,1999] at definite points and also 'the progonka equation' was tested on that paper whereas the other temperatures are from experimental works mentioned in the earlier authors' papers. The models were added new computed temperatures. It is, unfortunately, beyond the scope and purpose of this paper to present all the Junior author' considerations and statements regarding the true stress field at the ceramic/metal, ceramic/ceramic and truly composite joins; all that being generally in contradiction to or heavily modifying the common methods of (thermal) stress computation, and, basing on crystallochemical/mineralogical considerations. Several items will be signalised, either! Anyhow, let us take the coefficient of thermal expansion (CTE). The true such the coefficient at the surface of crystal or polycrystal should in many cases be higher than in the bulk – this being also known from literature quoted, e.g. by [Stepanov at al. 1984]. Many other contradictions to the common comprehension of (thermal) stress are to be found there thence the conclusions from the ANSYS computation are deemed only a rough estimation of the "joining power" of the materials investigated. Experiments prove useful. Of course, the CTE data input to ANSYS, even computed, are those without additional surface CTE effects. Many carbide – steel joins in spite of being the result of delocalisation of electrons (solid solutions) should undergo spallation when the CTE of components are regarded; the carbide CTE being very low – and they do not! Further, it should be stressed that adding a compound with lower molar volume than the host compound – to the host may, in some cases, promote expansion of the resulting crystal structure. Also, at the niveau of atom , an addition of a high field cation to the host crystal structure should promote lowering of the oxidation state of the host cation – thence a swelling of the structure – a process not regarded or simply unknown to the contemporary material scientists and chemists. Basing partly on the paper of [Ramberg, 1961] and knowing some problems of mineralogy and materials science, one can attain to the conclusion that a material with low compressibility partly (hardness) submerged in a one of high compressibility will be arrested (clogged) in the latter (circumferential compression stress).Thence, a joining in this way should be possible according to the Junior author's opinion. Already, an interesting paper [Stepanenko et al., 2005] describes production of diamond-SiC composite and using compressibility in a bit other, but similar purpose/way. It was stated there that diminishing of residual stress was due to increasing in multiplicative term of inverse compressibility, CTE difference and their difference in temperature. In short, difference in compressibility assisted lowering of stress and production of composite (under pressure) – otherwise incomprehensible composite! In new theories of complex heat transfer, there compressibility also comes into being. Besides, using anionic force of [Grassely, 1965], one can (after studies) attain to the conclusion that enhancing of CTE is possible by adding a 'more cationic' admixture to a 'more acidic one', e.g. adding Al_2O_3 to Al_2TiO_5 one can enhance CTE (exactly, a known process!). By means of this, one can, perhaps, explain the superplasticity of TiO_2-doped zirconia, toughening of alumina by niobium oxides or good mechanical properties of magnesia-doped alumina. All that process performs at the interfaces (supposedly). At any rate, all the above odd processes as well as the rules of crystal chemistry, epitaxy (though we are operating on polycrystalline materials) was used while planning the sequence of ceramic materials to join metals /steel. Moreover, it was tried to use the materials deemed temperature-shock resistant, except ,perhaps, YSZ which is poor in this respect, but its properties can be improved ,also by giving a definite under layer (beneath it). Say, wolframite, (Fe, Mn) WO4 displays 'shock response' on [Tret'yachenko and Karpinos, 1986]'s graph of 3.80 – hence nothing, whereas, e.g. 'shock resistant...alumina' of about 11.5. It is also important that for a good construction material being (to our purpose, to join metal or other ceramics), the material should possess a high creation enthalpy and some other properties as similarity or affinity to crystal structure to the to-be-joined materials, similarity of motifs in the crystal structure, or, possibility to create a definite compound. In sum, there should be possibility to switching bonds between phases (materials) and to tend to mechanical langevity. Moreover, especially joining materials should be more metallic covalent than ionic. Specifically, one exhaust valve with composite (COMWYL) and two intake ones (DOLOT10 and DOLSZ4) were modelled. Starting from the combustion chamber side, the first one is building up as follows: Ca-rich feldspar (70% vol.)+$CoSi_2$ (30%) composite (6mm max.)\$Mn_5Si_3$ (1mm)\chromian valve steel. The first intake one: YSZ (4mm)\wolframite- (Fe, Mn) WO4 (1mm) pyroxene – clinoenstantite – $Mg_2Si_2O_6$ (1mm)\$Ni_2Si$ (1mm)\Ni-steel for high temperature (can be other one, CTE). Finally, the DOLSZ4 model is made of YSZ (5mm) scheelite- $CaWO_4$ (1mm)\the steel. The 'joining philosophy' behind is as follows. The YSZ should join wolframite by switching bonds of Zr to it and enhancing its CTE also due to other properties (zirconia – 'cationic'). It can also switch to scheelite – a compound is typical with zircon. Scheelite being a raw material for ferrotungsten, so there can be some problems with micro stresses (carbides), but poor joining to steel is not expected. Further, there should be no special problems to join oxides and pyroxene (intergrowths), nor it seems impossible to join pyroxene-silicide-steel (a known join in meteorites). Experiment and especially cycling (thermal shock test) are needed. The interceramics layers can be thinner, but it was tried to put several element of FEM into it. Some additional phases of high failure stress were not included into FEM computations, and, the Ni-silicide is given here by the way of example. The latter should be (partly) replaced by a cobalt compound. The input temperature for respective layers at COMWYL are 850, 140.14, 138.26 ^{0}C– the later are improbable (unitary process transient computation), but using heat film coefficient (graphs) are even worse. At the pin: cone-pin join – 800 the liner entrance – 344.04\the liner exit – 97.33\pin's top – 78. At faying surfaces – 758.02^{0}C. Likewise, DOLOT10: 700\208.51\104.80\38.7536\28- assumed, and, at the pin 25.04\50.12\74.38\77. Faying surfaces asymmetric load, 238.63 and 165.48 ^{o}C. At DOLSZ4 they are 700\209.41\120.33, and, at the join of the pin 30.34.

2. Results

As regards COMWYL the max deformation is 0.57 mm. The temperature field (Fig.1) is not easy comprehensible in techniques, the temperature computed in the middle are too low , but the pattern is surely more true than that from the Fig.5, where apparently no thermal barrier one can see, the highest temp of gases are of 800^{o}C; 1200 – in the chamber of this adiabatic hypothetical engine; 850 was measured. Fig.2. presents shear of –581 to +487, partly not true (crook). The axial stress (still cylindrical coord. system) is from –681.915 to +433.982. In the Fig.3. the hoop stress is depicted, generally acceptable, but very high on steel and a patch at Mn silicide join is about 1000 MPa. Likewise Fig.4. depicts the radial stress where all the structure, except Mn silicide is below +888 MPa. As regards DOLSZ4, the asymmetric temperature load is depicted in Fig.6, whereas the generally low stresses, radial, hoop and shear is depicted in Figs. 6-9. It should be stressed that YSZ in the centre of the valve (chamber side) is in huge compressive stress, whereas scheelite in tension of about 79-200 MPa; and above 330 from the steel side (all radial one, Fig.7.). The hoop stress, Fig.8, is generally from –562 to +287 MPa with some points beyond this interval, e.g. scheelite from the steel side is a bit above 286.629 MPa. The axial stress (not depicted is low, i.e. –232 to +203, but the highest tension (+154 to +203) being in steel as well as compression. The shear, Fig.9., -121 to +214 is very picturesque; tension only in steel. In general, the intake valves have cavity in the centre part of the 'fire-surface' of the cone. Hence, the huge compression stress there should vanish. Finally, the DOLOT10 which display much lower principal and 'shear at principal' stresses in contradistinction to the above ones, will also be regarded in terms of hoop, Fig.10-11., radial (Fig.12) , axial and shear (not depicted).The hoop stress can be large at the centre of YSZ, of –1000 MPa, but see above. Generally this stress is of –551 to +51 range with islands of the higher one; wolframite being +51 to +226 max., whereas the islands of +221 to +402 at diverse parts of ceramics and steel. It is better seen in Fig. 11., compression at the centre (YSZ) and tension at the rand, +402 MPa. The axial one is of –290 to +220 – low, +164 to+220 being in steel. Shear is low or extremely low. Fig.12. imagines radial stress, -703 (centre, YSZ, see above) to +401. The islands of highest one (+275 +401) in ceramics and steel are divided by strips of wolframite, enstantite and Ni silicide with 155.829 to 276.55 tension stress. Deformation of the intake valves is a bit lower than that of the exhaust valve.

3. Conclusion

The display of the temperatures and stresses is partly undergone unalteration, partly due to the fact of lack of computation of the temperatures (beyond FEM) at the slopes of the ceramics or composite cone, and, partly due to the fact that ANSYS11 is not sensitive to radiation in semitransparent materials. Thus, diverse temperature or stress maps with ‘the bowl inside’ appear strange and dangerous to an engineer, being however rounded by quite large compressive stress. Generally lower stress occurs or at the order of the failure stress of steels used, their tension stress and even, partly plasticity limit. It turned out that using some novelty chemical rules in building up the new adiabatic engine details, one can attain to the stresses commonly occurring in the common highly forced Diesel engines, i.e. in their valves – about 500 MPa. There are already several problems. It is difficult to cope with all the positive traits of material, e.g. the valves were hypothetically build up in such a way to diminish radiation into deeper layers, metal. However, not all the materials are strengths enough and good reflector, simultaneously. Especially, YSZ may or may not withstand huge compressive stress. It can be alleviated or YSZ abandoned. The composite will surely do, especially when reinforced with Co-Co_3Si join, the failure stress of which being 973.8 MPa at 500^{o}C. But more metallic composites may partly give a bit poorer thermal barrier. Also Ni-silicide can be replaced by cobalt one, though having quite large E, 160.88GPa. Wolframite should withstand about 150-200 MPa, but owing to the couple with YSZ and structure – more. Scheelite and pyroxene should withstand more than expected from their hardness, since their E moduli are 166.3 and 228.04 GPa, resp. It should be stressed that all the stresses can be lower in reality due to the minerals formation compressive stress, and, especially, due to anisotropic approach in the ongoing projects. Here, in spite of knowledge of the phases, only the isotropic approach was used in 3D FEM. One can also protect the exhaust valve from the channel side. The temp. dependence of the input values is such that phase transformations were not taken into account. Of course, one can detect endothermic transformation in feldspar which promotes gain of the temperature drop.

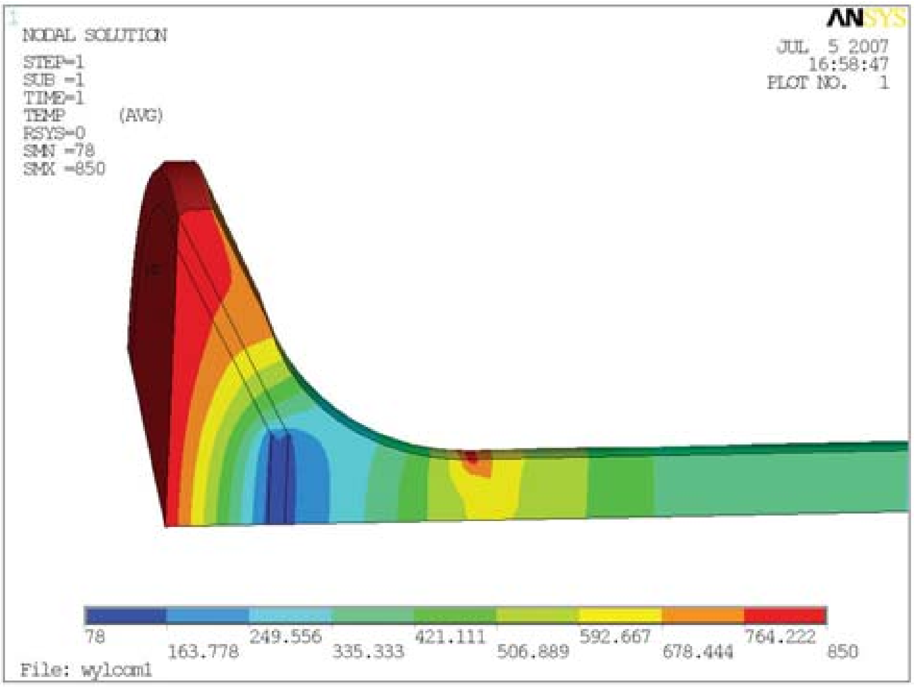

Fig. 1. COMWYL temperature field

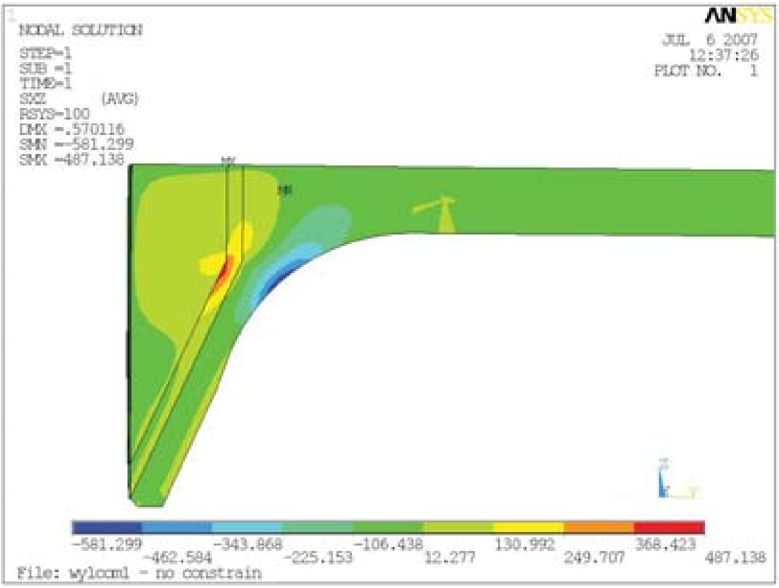

Fig. 2. COMWYL, shear

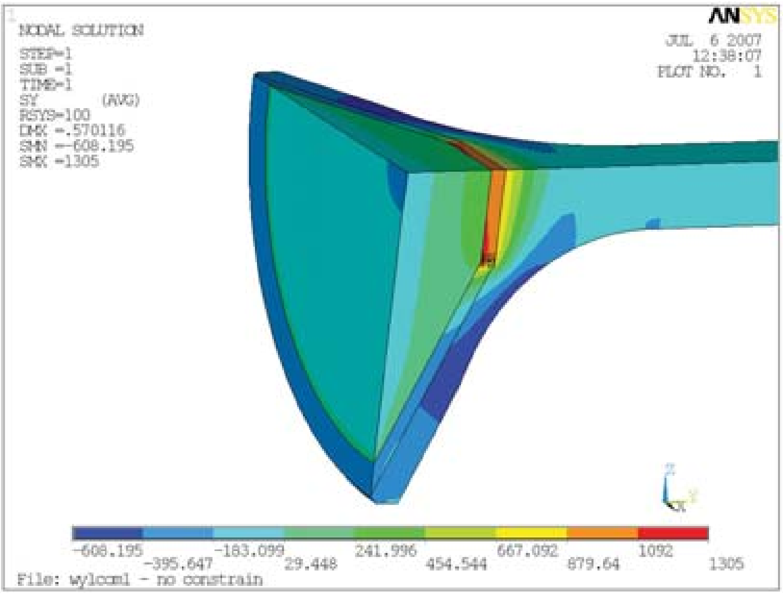

Fig. 3. COMWYL, hoop stress

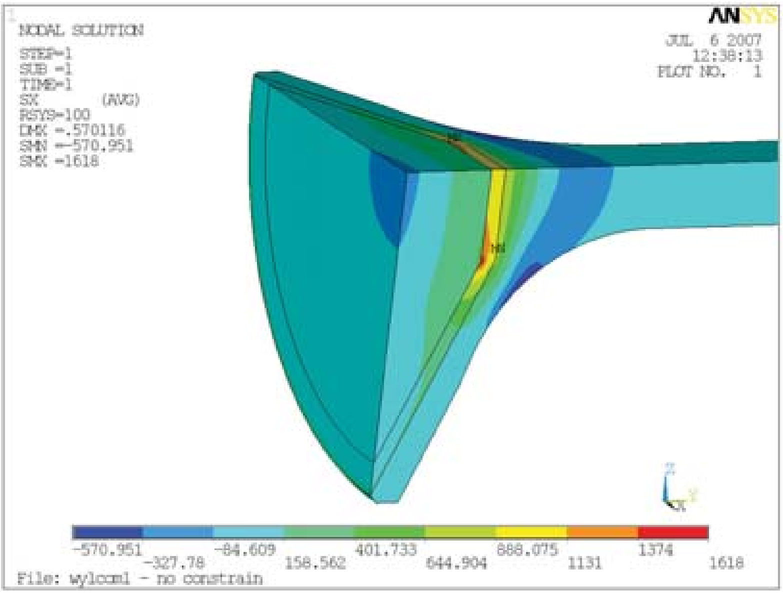

Fig. 4. COMWYL,radial stress

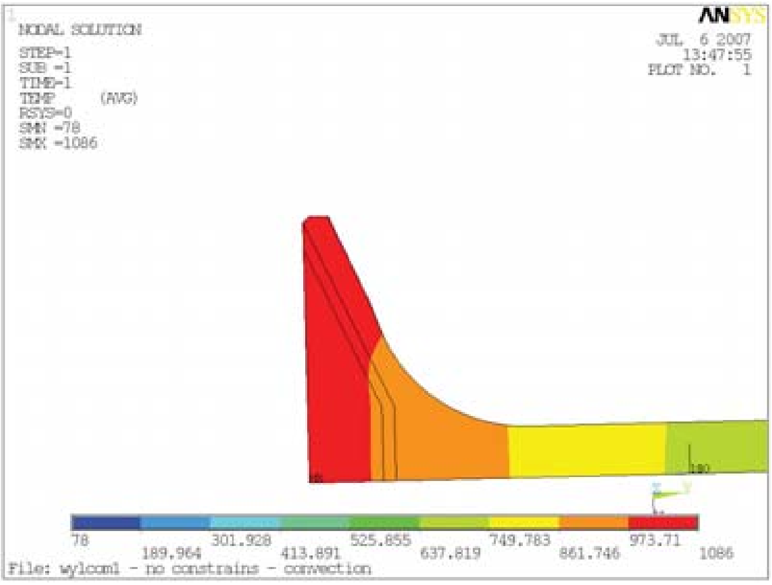

Fig. 5. Temperature from convection

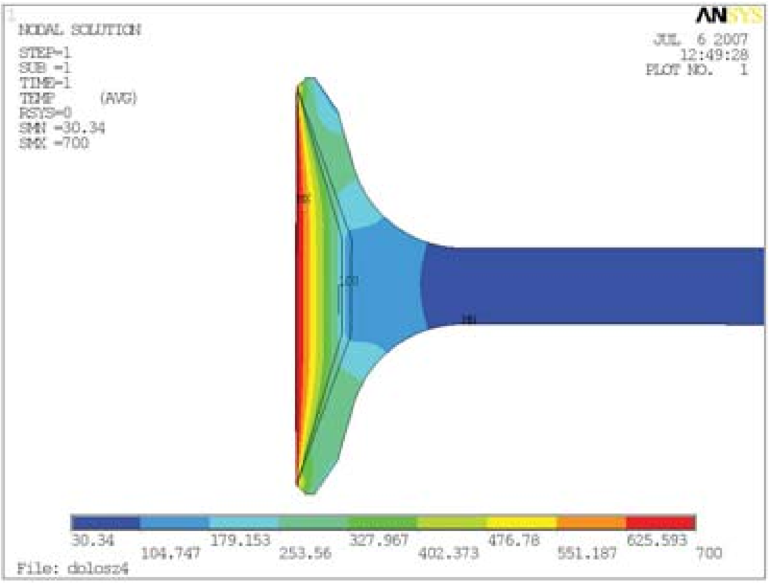

Fig. 6. DOLSZ4, temperature field

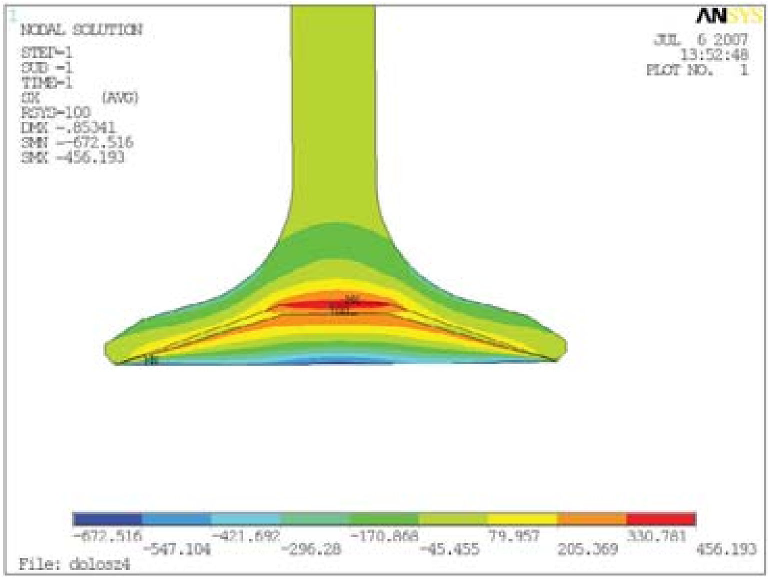

Fig. 7. DOLSZ4, radial stress

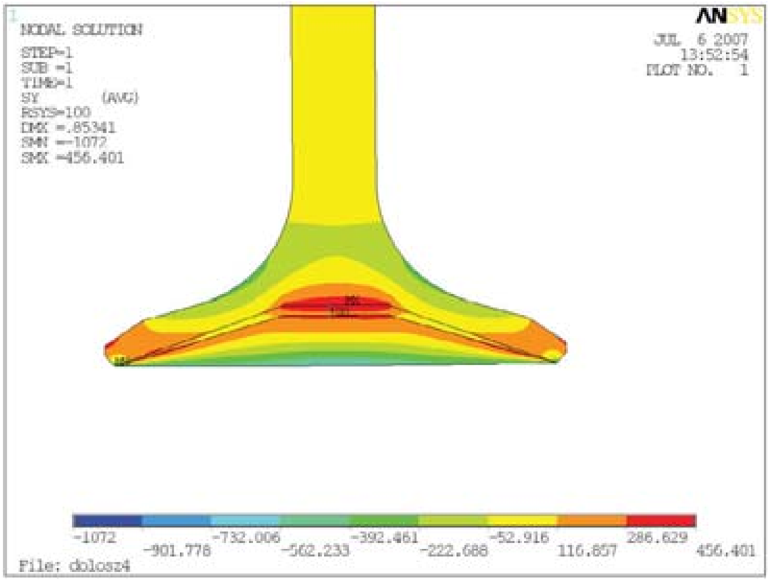

Fig. 8. DOLSZ4, hoop stress

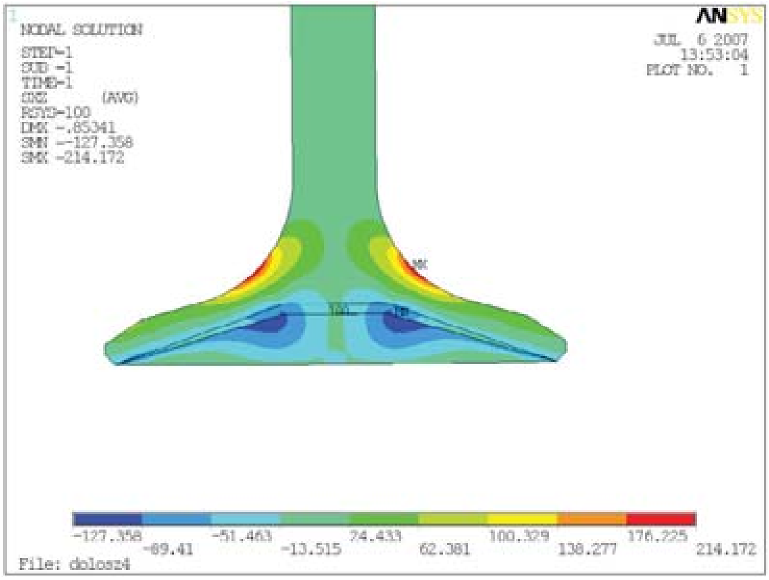

Fig. 9. DOLSZ$, shear

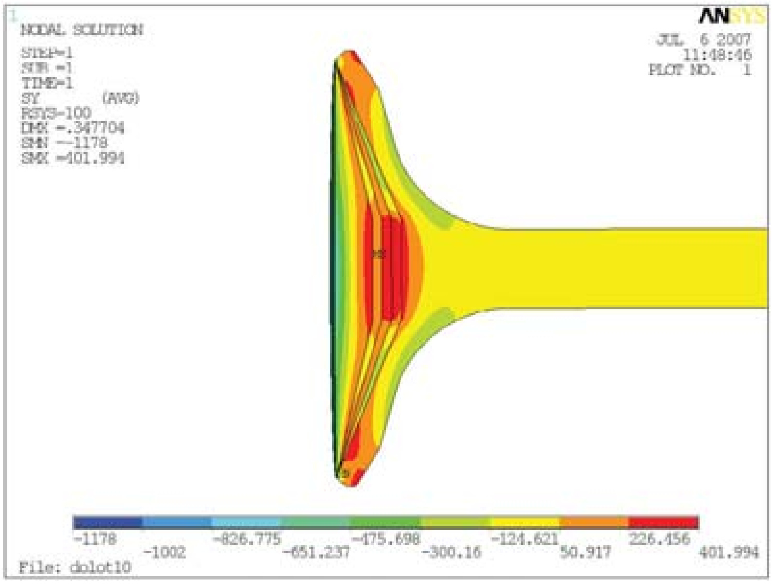

Fig. 10. DOLOT10, hoop stress

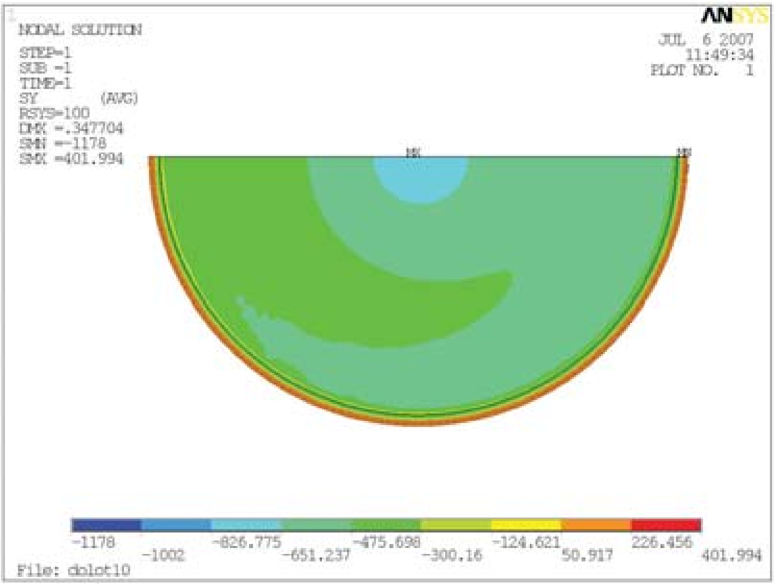

Fig. 11. DOLOT10, hoopstress, chamber side

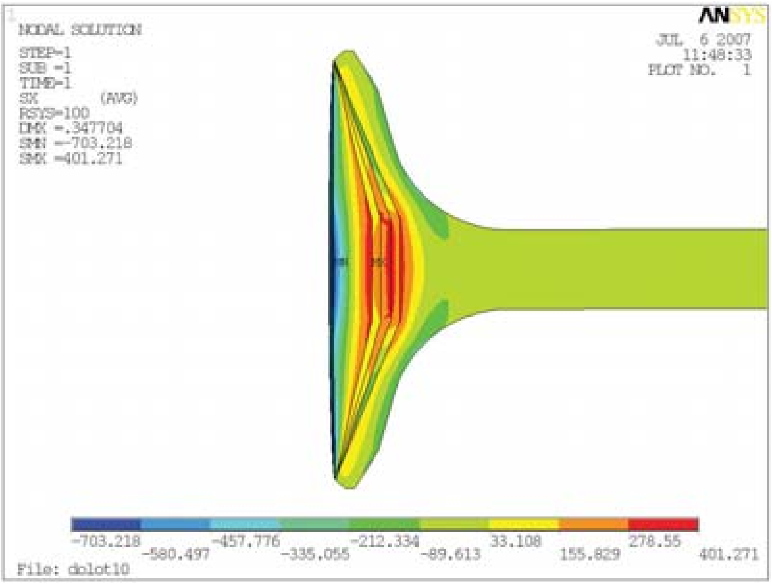

Fig. 12. DOLOT10, radial stress

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