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Vpliv obremenitev na tesnilko glave motorja
Influence of Different Stresses on the Head Gasket

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Na delih motorja se pojavljajo različne deformacije, ki jih povzročajo masne, tlačne in toplotne sile. Članek obravnava predvsem vpliv sil na tesnilko glave motorja, s posebnim poudarkom na deformacijah, ki jih povzroča tlak plina. Z uporabo modela iz poliakrilnega stekla in modeliranja na računalniku so prikazane deformacije, ki se pojavljajo pri različnih obremenitvah. Posebno pri modeliranju se je pokazala velika podobnost med signalom poteka tlaka v valju in signalom za deformacije na tesnilki. Predvidevanje je torej potrdilo spoznanje, da je mogoče tesnilko uporabiti kot nosilni element za zaznavalo, ki posredno prek deformacij tesnilke meri tlak v valju.

On each part of an engine different deformations appear, caused by mass, pressure and thermal forces. This paper deals with the deformations in head gasket with the emphasis on the pressure variations in the cylinder. Physical and computer models of the problem show the essential signal transition through the gasket. The recorded signals, one from the cylinder pressure sensor and the second from the deformation sensor on gasket were very similar in form, but not in amplitude. So engine control is currently quite possible, by the head gasket as a carrier for a sensor which senses pressure in the cylinder.

0. UVOD

Tesnilka glave motorja je navidezno preprost element, ki ima pomembno vlogo, to je tesnjenje oziroma ločitev zgorevalnega prostora od okolice. Zaradi lege med glavo in okrovom motorja delujejo na tesnilko različne sile, ki ga deformirajo, in sicer predvsem v elastičnem območju.

Poglavitno vprašanje, ki smo si ga zastavili, je, da želimo poiskati povezavo med deformacijami tesnilke in povzročitelji. Predvsem nas zanima v tej zvezi sprememba tlaka v valju in nato vplivi na tesnilko.

Če govorimo o deformacijah na tesnilu, moramo problem nekoliko poenostavljeno razdeliti v več faz ali dogodkov.

Prve deformacije na tesnilki se pojavijo pri njeni vgradnji v motor, torej takrat, ko privijemo glavo. To so predvsem plastične deformacije. V tem primeru se deformacije ustalijo po končanem privijanju glave, deloma pa po nekaj urah delovanja motorja, ko se tesnilka prilagodi. Zato tudi lahko vzamemo to bolj kot lokalno prilagajanje tesnilke prostoru, ki ga lahko zavzame. Kljub temu ostane tesnilka še vedno dovolj elastična, da dobro tesni.

Druga faza deformacij se pojavi potem, ko motor doseže svojo delovno temperaturo. Pri tem nastane nova slika tlakov na površino tesnila, kar pomeni na nekaterih mestih še dodatne plastične

0. INTRODUCTION

A head gasket seems to be a very simple element, but which has an important role in sealing or separating the combustion chamber from the environment. Due to its position between the head and the housing of the engine, there appear different forces that deform it, especially in its elastic domain.

The basic aim was to seek the link between the gasket deformations and their cause. One is especially interested in cylinder pressure changes and their influences on the gasket.

In terms of deformations on the gasket, the problem has to be divided into different phases.

First, deformations of the gasket appear when it is mounted on the engine, i.e. when the head of the engine is tightened. In this case we speak of plastic deformations that are partly established after the head is tightened, and partly after the engine has been working for some hours, when the gasket fits the engine. We can therefore speak of local adaptation of the gasket to the available space, while the gasket remains elastic enough to have good sealing qualities.

The second phase begins when the engine reaches its working temperature. There are different pressures on the gasket surface. On some spots we get additional plastic deformations, on others there is discharge. After the gasket deformacije, drugod pa razbremenjevanje. Ko tesnilka sede, dobi neko končno obliko glede na plastične deformacije, ki se dejansko še vedno pojavljajo, vendar v zelo omejenem obsegu. Če se pojavijo plastične deformacije v kritičnem obsegu, je taka tesnilka uničena. To se zgodi v normalnih razmerah po nekaj sto tisoč kilometrih. Po končanem začetnem prilagajanju tesnilke lahko upoštevamo, da se praktično pojavljajo samo še elastične deformacije.

Morda lahko prvi dve fazi pogojno ločimo od tretje po tem, da pri njiju bolj poudarjamo deformacije po debelini oziroma višini tesnilk.

Tretja faza deformacij pomeni za nas elastičnost tesnilk med delovanjem, kjer gledamo predvsem radialno smer glede na os valja. Te deformacije povzroča predvsem tlak v valju, motilne sile pa delujejo na površino tesnilk. Vendar so te sile v nekakšni odvisnosti s plinskimi silami in nimajo bistvenega vpliva na obliko deformacijskega signala.

Zaradi navidezno nemotenega prenosa tlaka v valju prek deformacij na tesnilki, se je pojavilo vprašanje o možnosti posrednega merjenja tlaka v valju. Seveda bi bilo tako merjenje tlaka zanimivo, če bi bilo zanesljivo in poceni. Zato je v delu prikazan potek deformacij na tesnilki in možnih prostorih za vgradnjo zaznaval.

1. REŠEVANJE PROBLEMA IN REZULTATI

Pri reševanju problema smo se odločili, da gledamo v obsegu, ki je za nas zanimiv. Tesnilko smo vzeli kot ploskovni element (dvodimenzionalni), na katerem se pojavljajo elastične deformacije, torej v ravnini. Kljub temu v določenih primerih upoštevamo vpetje tesnilke med okrov in glavo motorja, pri delovni temperaturi.

Podatke o stanju tesnilke smo dobili z meritvami in zaznavali, ki so bila vstavljena v tesnilko ali nanjo.

Eksperimentalno smo ugotavljali deformacijsko stanje tesnilke z uporabo modela iz poliakrilnega stekla v naravni velikosti. Na modelu smo simulirali tlak v valju, tlak na površino v okolici valja in tlak na površino v okolici vijakov glave. Ker ima poliakrilno steklo določene optične lastnosti, kadar ga obremenimo, se v odvisnosti od tega pojavijo na površini modela svetlejša in temnejša mesta; seveda, če opazujemo model s polariskopom. Svetlejša in temnejša mesta modela se lahko prikažejo tudi kot paleta barv z določenim razporedom, ki kažejo razliko glavnih napetosti [1]. Na sliki 1 vidimo primer, pri katerem je simuliran tlak v valju 50 bar, oziroma temna in svetla področja, kjer potekajo različne napetosti.

»settles down«, it obtains its final shape in relation to the plastic deformations. The deformations still appear, but they are not important. If the deformations reach a critical level, the gasket becomes defective. In usual conditions, this happens after some thousand kilometers. After the initial adaptation of the gasket, we can count only on elastic deformations.

The first two phases can be conditionally separated from the third, since we stress the deformations of height and thickness of the gasket.

The third phase of deformations represents the elasticity of the gasket during operation, where we first observe radial directions to the cylinder and disturbing forces act on the surface of the gasket. These forces depend on gas forces and have no essential influence on the basic shape of the pressure deformation signal.

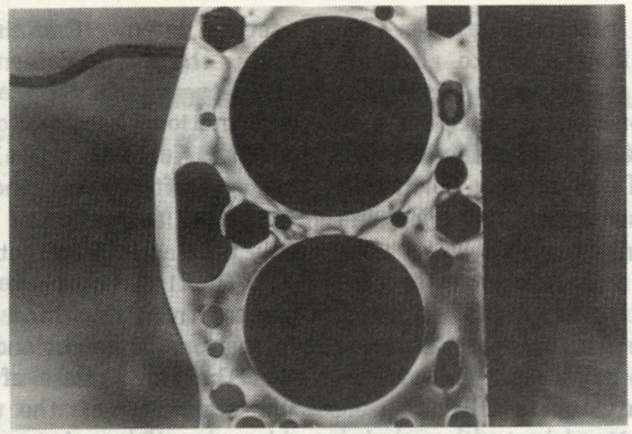
Due to apparently undisturbed pressure transfer through deformations of the gasket, the question is raised as to the possibility of indirect measurement of the pressure in the cylinder. Such measurement would of course be interesting only if it was reliable and low-priced. This paper describes the problem of gasket deformation and possible locations at which to install sensors.

1. SOLVING THE PROBLEM AND THE RESULTS

We decided to restrict the problem to the scope which is of interest to us. The gasket was taken as plane element (2-D), on which there appear elastic deformations, in plane and not in height. Nevertheless, in some cases also the clamping of the gasket between the head and the housing of the engine at operating temperature was taken into account.

The data about the condition of the gasket were received from the sensors, installed in or on the surface of the gasket.

Experimentally, with a synthetic glass natural size model we determined the state of the gasket deformation. The pressure in the cylinder and the pressures near the head screws were simulated on the model. Since synthetic glass has specific optic qualities when charged, there appear on the model surface certain darker and lighter spots when viewed through a polariscope. These lighter or darker spots can be graded from black to white colour, or are shown as a certain order of colours. They show stresses or, more precisely, the difference of the principal stresses as shown in figure 1, which presents an example of simulation (the cylinder pressure is 50 bar).



Sl. 1. *Primer obremenitve modela (tlak v valju 50 bar)*
Fig. 1. *The stress pattern by pressure at 50 bar*

Vrednotenje slike je mogoče iz barvnih fotografij, vendar ne preveč natančno, ker uporabljeni material nima optimalnih optičnih lastnosti. V glavnem se namreč poliakrilno steklo uporablja bolj za demonstracijske prikaze dogajanja v materialu, če ga obremenimo s silo.

Slikovno gradivo kaže relativno zelo široko področje enakomernih obremenitev in le okoli zarez in izvrtin se pojavljajo napetostni skoki. To pomeni, da je mogoče najti mesto za zaznavalo na razmeroma ugodnem mestu, ki je enakomerno obremenjeno, kar pomeni tudi večjo zanesljivost pri prikazovanju merjenega signala.

Drug način obremenitve tesnilke je bil narejen z računalniškim modeliranjem. V ta namen je bil uporabljen ustrezen program po metodi končnih elementov (MKE). V tem primeru so bili izbrani nekateri prerezi skozi tesnilko, za katere menimo, da so zanimivi glede postavljanja zaznaval, kar prikazuje slika 2. Prerez (1, 2, 3) na tej sliki, ki je označen od vozlišča 379 v smeri vozlišča 32, kar hkrati pomeni v tem primeru os y tako postavljenega koordinatnega sistema.

Razlika deformacij tesnilke v primeru, ko je obremenjena na površini in v primeru, ko površinskih tlakov ni, je prikazana na sliki 3. V diagramu pomeni krivulja, označena s krogci, spremembe glede na os y, in s trikotniki glede na os x.

Zaradi lažjega predstavljanja preoblikovanja tesnilke v primeru, ko nanjo delujejo sile, je bilo narejeno simuliranje deformacij. Na slikah 4 in 5 je predstavljena mogoča deformacija tesnilke, če je v valju tlak 50 bar.

V prvem primeru je delovanje tlaka prikazano, če je aktiven prvi valj, in v drugem primeru, če je aktiven drugi valj.

Primerjava med modelom iz poliakrilnega stekla (sl. 1) in računalniškim modelom (sl. 6) prikazuje razliko glavnih napetosti.

The evaluation of the picture material the light spots present the course of different in our case is possible from colour pictures, yet it is not very accurate, because the material used does not have the optimum optic qualities, since synthetic glass is used more to demonstrate what is going on in the material when stressed with some force.

The picture material shows relatively wide areas of equal stresses with leaps only around cuts and drills. This means that a sensor can be installed in a relatively satisfactory place, where it is equally stressed and the measured signal is reliable.

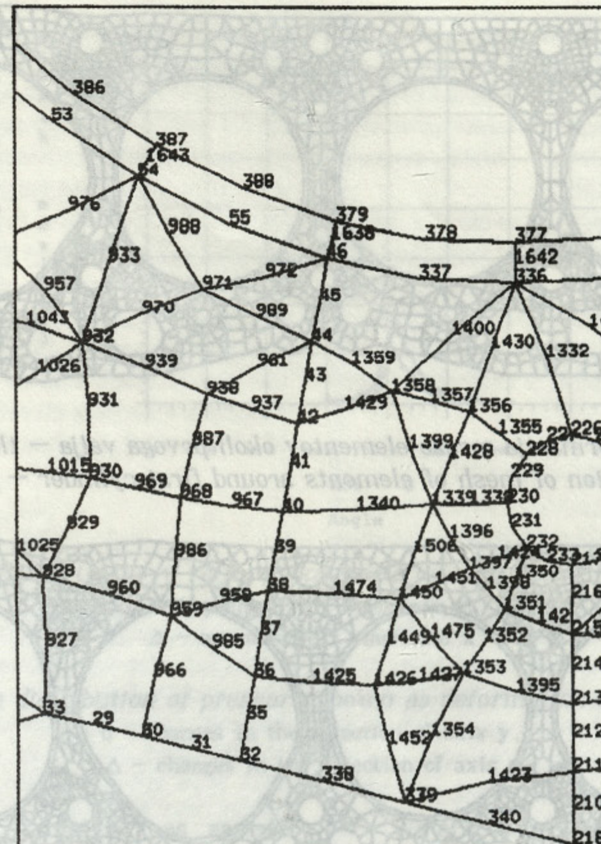
The second way of simulating stress on the gasket was by computer modelling. We used appropriate software which uses the finite element method (FEM). In this case we took some sections that we assumed to be interesting for possible sensor installation (fig. 2). The section on figure 2 is marked by (1, 2, 3), and runs from node 379 in the direction of nodes 32 and at the same time represents the y-axis of the coordinate system.

The difference in deformations on the gasket when it is stressed on the surface (similar to when engine is operating) and when there are no surface pressure is shown on Figure 3. The curve marked by circles in the diagram shows the differences about axis y and with triangles with references to axis x.

For better presentation of gasket deformation when the forces are acting on it we made a simulation of the deformations. Figures 4 and 5 show possible deformation with a cylinder pressure of 50 bar.

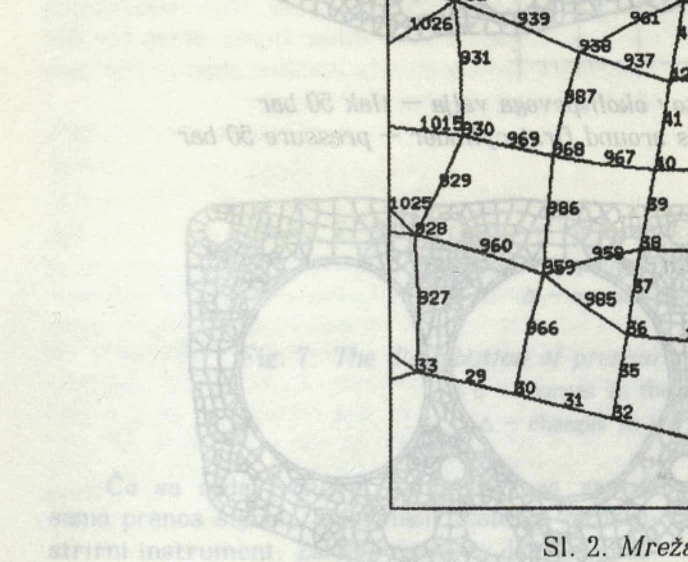
In the first example, the action of the pressure is shown when the first cylinder is active, and in the second example, when the second cylinder is active.

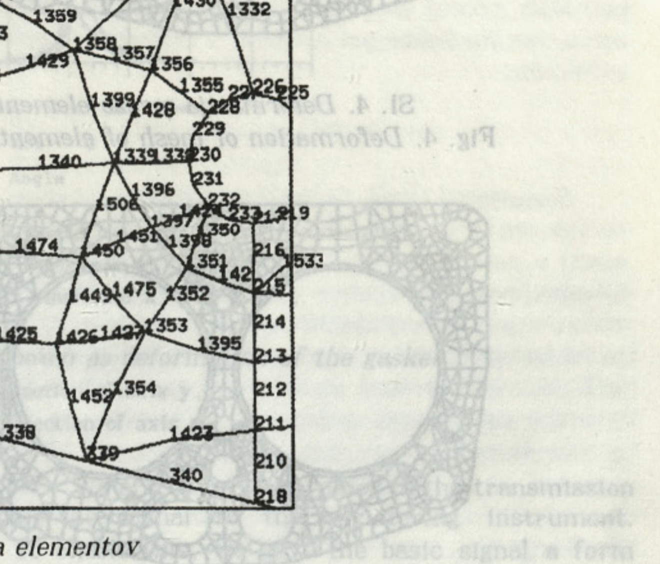
Direct comparison between the synthetic glass model (fig. 1) and the computer model (fig. 6) is possible by the presents the difference in the principal stresses.



Sl. 2. *Mreža elementov*

Fig. 2. *Mesh of elements*





a) b)

Sl. 3. *Deformacije v radialni smeri*

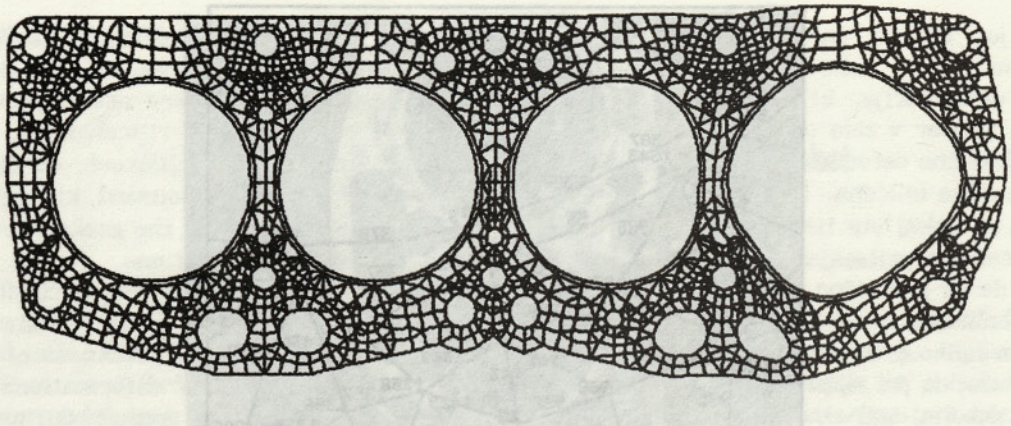
a) pri neobremenjeni tesnilki, b) pri obremenjeni tesnilki

o – spremembe v smeri osi y, Δ – spremembe v smeri osi x

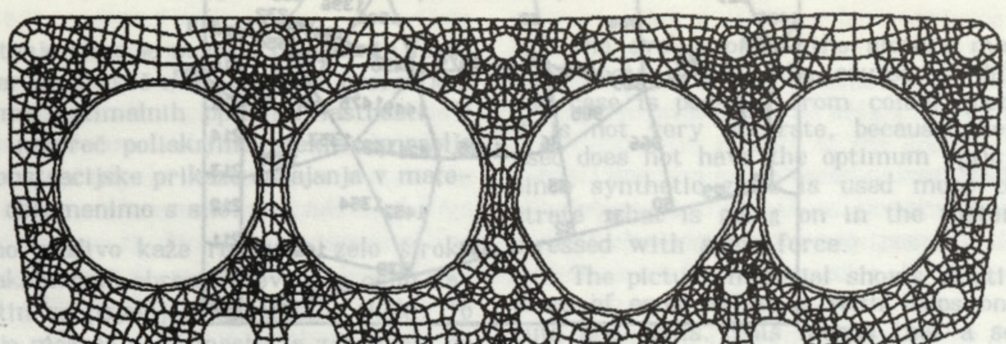
Fig. 3. *Deformations in the radial direction when the gasket is*

a) not under pressure, b) under pressure

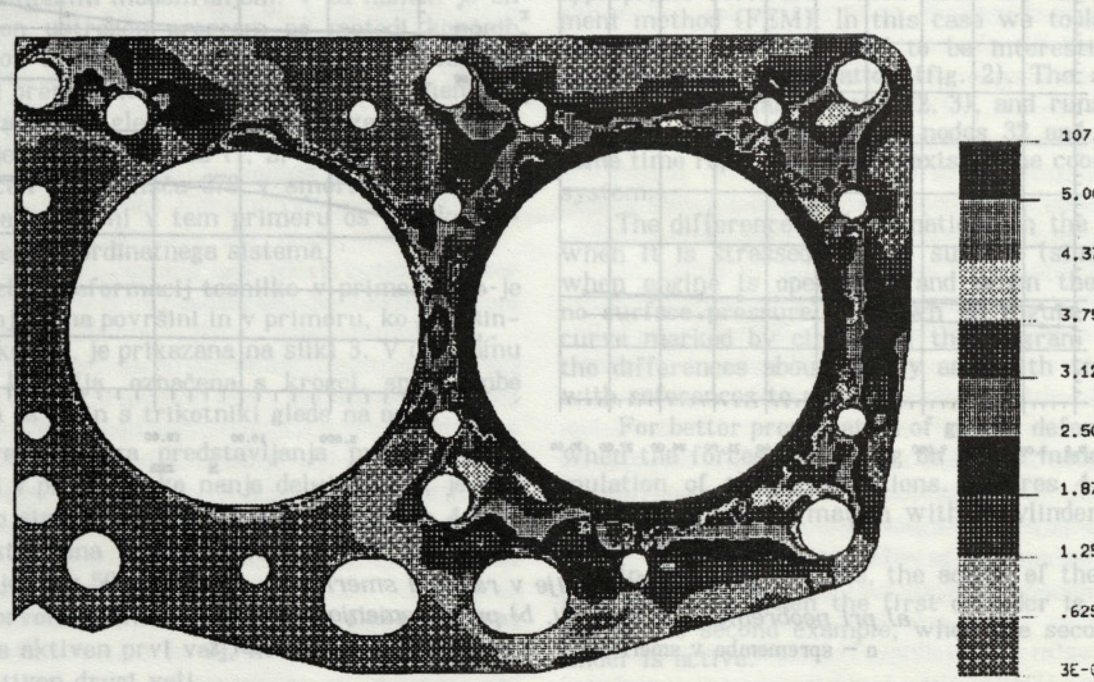
o – changes in direction of the axis y, Δ – changes in direction of the axis x



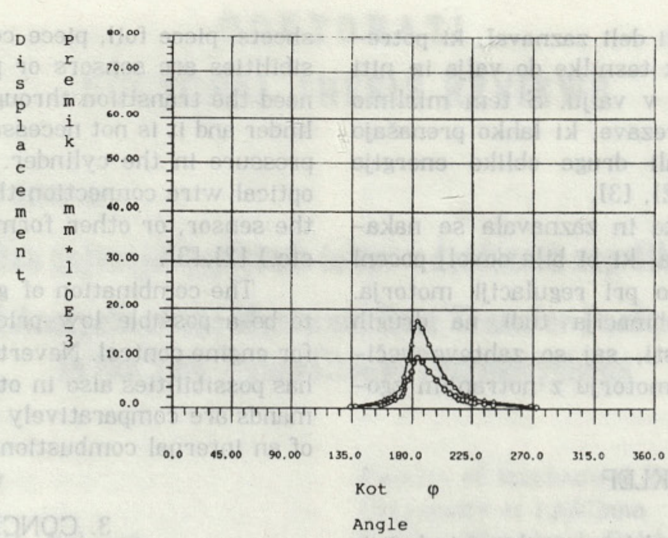
Sl. 4. *Deformacija mreže elementov okoli prvega valja – tlak 50 bar*
Fig. 4. *Deformation of mesh of elements around first cylinder – pressure 50 bar*



Sl. 5. *Deformacija mreže elementov okoli drugega valja – tlak 50 bar*
Fig. 5. *Deformation of mesh of elements around second cylinder – pressure 50*



Sl. 6. *Porazdelitev napetosti pri tlaku 50 bar*
Fig. 6. *The stress patterns at the pressure of 50 bar*



Sl. 7. *Potek tlakov v valju, prikazan na tesnilki kot deformacija*
o – spremembe v smeri osi y,
Δ – spremembe v smeri osi x

Fig. 7. *The distribution of pressure shown as deformation of the gasket*
o – changes in the direction of axis y,
Δ – changes in the direction of axis x

Če se sedaj vrnemo k bistvu, nas zanima samo prenos signala deformacij tesnilke na registrirni instrument. Zaradi tega smo dali osnovnemu signalu neko obliko, ki ponazarja spremembo tlaka v valju, in spremljali, kaj se dogaja s to obliko na tesnilki, ko prikazujemo ta signal kot deformacijo. Kakšno obliko deformacije smo dobili v radialni smeri in pravokotno na radialno smer, je prikazano na sliki 7.

Prva ugotovitev, ki izhaja s slike je, da se oblika signala zelo dobro prenaša, kar pa ne velja za amplitudo.

Iz izkušenj lahko povzamemo, da je tesnilka motorja zanesljiv element, ki vzdrži zelo dolgo, torej je tudi oblika deformacije bolj ali manj nespremenljiva. V trenutku, ko tesnilka ne tesni več, izgubi svojo vlogo.

2. OBRAVNAVA REZULTATOV

Vidimo torej, da je mogoče tudi na motorju izkoristiti tesnilko kot posreden vir informacij o dogajanju v valju. Tlačni signal je pomemben zaradi možnosti regulacije poteka procesa v valju, posebej še, če želimo uvesti prilagodljivo krmiljenje.

Ker želimo zaznavalo, ki bo poceni in zanesljivo, poleg tega pa imamo opraviti še z zahtevami glede geometrijskih oblik, smo pri izbiri zaznaval nekoliko omejeni. Glede izmer smo vezani na višino, kar pomeni, da mora biti zaznavalo v obliki folije, kakršni so uporovni lističi, piezofolija, piezokeramika, polprevodniški upori itn. Druga

We are mainly interested in the transmission of the signal to the registering instrument. To enable this, we gave the basic signal a form which illustrated the change of pressure in the cylinder and observed the form and amplitude of the gasket, when the signal was shown as a deformation in the radial direction and at right angles to the radial direction (fig. 7).

The first point which is clear from the figure is that the basic signal is very well transmitted, but not the amplitude.

From experience we can assume that the gasket is a very reliable element of the engine, of long life, so the deformation is approximately constant. When the gasket no longer seals, it loses its role.

2. DISCUSSION OF RESULTS

As described in the paper the head gasket can be used as an indirect source of information about what is going on in the cylinder. The pressure signal is important because of the possibility to control the process in the cylinder, especially if we want to introduce adaptive controlling.

Because we need a sensor which is low priced and reliable and we have some geometry demands to respect the choice of sensors is rather limited. The dimensions of the sensor that should be rather in the form of foil, such as the resistor možnost so zaznavala ali deli zaznaval, ki potrebujejo samo prehod prek tesnilke do valja in niti ni treba, da merijo tlak v valju. S tem mislimo predvsem na optične povezave, ki lahko prenašajo do zaznaval svetlobo ali druge oblike energije (zvočno, toplotno itn.) [2], [3].

Kombinacija tesnilke in zaznavala se nakazuje kot mogoča različica, ki bi bila dovolj poceni in zanesljiva za uporabo pri regulaciji motorja. Vendar ima taka kombinacija tudi na drugih področjih precej možnosti, saj so zahteve večinoma manjše kakor pri motorju z notranjim zgorevanjem.

3. SKLEP

Rezultati, ki so le deloma prikazani, kažejo na povsem stvarno možnost zanesljive poti informacij o poteku tlakov v valju. Čeprav je pot informacij posredna (valj — tesnilka — instrument), ohrani signal dovolj značilno obliko in značaj, da bi ga lahko uporabili pri regulaciji motorja. V prvem približku je kakovost signala v tem, da časovno bistveno ne zaostaja za dogajanjem v valju, oblika je zelo skladna s signalom, zaradi dušenja, ki se pojavlja na posredniku, pa ni mogoče podrobno spremljati nekaterih pojavov v motorju, na primer klenkanja.

Na voljo imamo dovolj zaznaval, ki bi utegnila biti zanimiva za predstavljeno kombinacijo tudi glede cene in zanesljivosti. Izkazalo se je, da mesta za postavitve zaznaval niso mesta s posebnimi lastnostmi, ampak povsod tam, kjer je dovolj prostora zanje.

sheets, piece foil, piece ceramics etc. Other possibilities are sensors or parts of them that only need the transition through the gasket to the cylinder and it is not necessary for them to measure pressure in the cylinder. We think especially of optical wire connection that transmit the light to the sensor, or other forms of energy(sound, heat etc.) [2], [3].

The combination of gasket and sensor seems to be a possible low-priced and reliable solution for engine control. Nevertheless, this combination has possibilities also in other fields, since the demands are comparatively smaller than is the case of an internal combustion engine.

3. CONCLUSION

The results, partly shown in this paper demonstrate the possibility of a reliable source of information about the pressure in the cylinder. Although the source is indirect, the signal preserves its form and character, sufficiently to be used for engine control. In the first approximation, the quality of the signal lies in the fact that it is simultaneous to the process in the cylinder and the form is consistent with the basic signal, but because of damping, it is not always possible to follow some phenomena in the engine, knocking for example.

There are some sensors that might be interesting for the above combination from the point of price as well as reliability. It was demonstrated that the possible places of sensor installation are not places with special characteristics, but wherever there is space enough for them.

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