Journal of KONES Powertrain and Transport, Vol. 18, No. 2 2011

THE MAGNETICALLY LOADED NONCONTACT COUPLE BETWEEN VALVE TIP AND SURFACE OF CAM FOLLOWER OR ROCKER ARM

Krzysztof Siczek

The Technical University of Lodz
The Department of Vehicles and Fundamentals of Machine
Zeromskiego Street 116, 90-924 Lodz, Poland
tel.: 0426312250, fax: 0426312252
e-mail: ks670907@p.lodz.pl

Abstract

The lightweight valves are more and more commonly used in cam and camless valvetiming in combustion engine. They can be made as drilled steel valves or as full but of TiAl alloys or of ceramic material. They usually can mate with the same valve guides and seat inserts made of cast iron, as in case of the standard full steel valves. Sometimes in the high speed engine, the valve insert should be made of chromium steel and valve guides of phosphorous bronze. The one of sources for wear and for resistance of motion for valve is a friction contact area between the valve tip and the surface of rocker arm or of cam follower. To minimize the wear the valve tip should be hardened or have a special hard cup, which makes greater mass of the valve. To avoid the wear and friction resistance in such contact area the mentioned friction contact can be eliminated. Such friction contact type can be replaced by a noncontact couple loaded by magnetic field force. Such solution requires introducing the set of the cylindrical permanent magnet fixed to nonmagnetic valve tip and of the similar magnet fixed to the bottom face of a cam follower or of the set of small plane magnets on the cam surface. The cam should be made of nonmagnetic material either. The model of such assembly of magnets has been made with the help of the finite element method. The values of magnetic force loading noncontact couple have been obtained for some configurations of magnets and for different positions for elements of valvetrain and presented in the article.

Keywords: *combustion engine, valvetrain elements, permanent magnets, noncontact couple*

1. Introduction

In the majority of combustion engines, valves made of steel are commonly used. But recently the lightweight valves have been met in the modern valve train in combustion engine. Such valves could be observed in camless valve trains and in those with the classical camshafts, either. The geometry of camless valve train has got specific properties, sometimes different in comparison to those of camshafts. The head difference has been the shape of valve profile, which has been similar to the trapezoid one. The valve lift and valve duration could be different and could vary during valve cycles. A quick action of camless valve drive can be obtained particularly by use of electromagnets or permanent magnets as elements of valve drive [3]. Because of relatively high costs, the camless solution is not so popular, but there are a lot of quick solutions based on classic camshaft, with fully variable valve train and/or lift control.

For conventional valvetrains with camshafts, the mean problem has been the wear and resistance of motion. The one of sources for such wear and resistance is a friction contact area between the valve tip and the surface of valve lifter, rocker arm or of cam follower, dependently on design. To minimize the wear the valve tip should be hardened or have a special hard cup, which makes greater mass of the valve. To avoid the wear and friction resistance in such contact area the mentioned friction contact can be eliminated. Such friction contact type can be replaced by a noncontact couple loaded by magnetic field force. Such solution requires introducing the set of the cylindrical permanent magnet fixed to nonmagnetic valve tip and of the similar magnet fixed to the bottom face of a valve lifter or of the set containing small plane magnets on the cam surface. The cam should be made of nonmagnetic material either.

The numerical analysis has been carried out, where the object has been the nonmagnetic elements of valve train in combustion engine. Those elements have been valve, valve guide and seat insert. The analysed valves have been driven by special camshaft, with the cams of specific shape. The cam profile has been presented in the Fig. 1. The analyzed valves have been made of TiAl – alloy. The analyzed valve guides have been made of cast iron. The analyzed seat inserts have been made of cast iron, as well. The valves have mated with their guides and their seat inserts in the conditions of oil absence. The valves have mated with their springs, made of titanium alloy. The analysis has been carried out for assumed constant camshaft rpm.

The aim of the analysis has been to obtain values of magnetic force loading mentioned noncontact couple for some configurations of magnets and for different positions for elements of valvetrain.

The results of numerical analysis obtained for different materials for permanent magnets have been presented in the article.

2. Cam shape

The shape of analyzed cam 1 has been presented in Fig. 1. A set of permanent magnets 2 has been positioned on the cam surface. The cam 1 has mated with valve lifter, which contains permanent magnet 3. The several position points of the magnet 3, relative to the cam 1, have been presented in the Fig. 1. The magnetic field of magnets has been directed radial to the Z axis. The direction of magnetic field for cam magnets 2 has been nearly opposite to the one for magnet 3 of valve lifter.

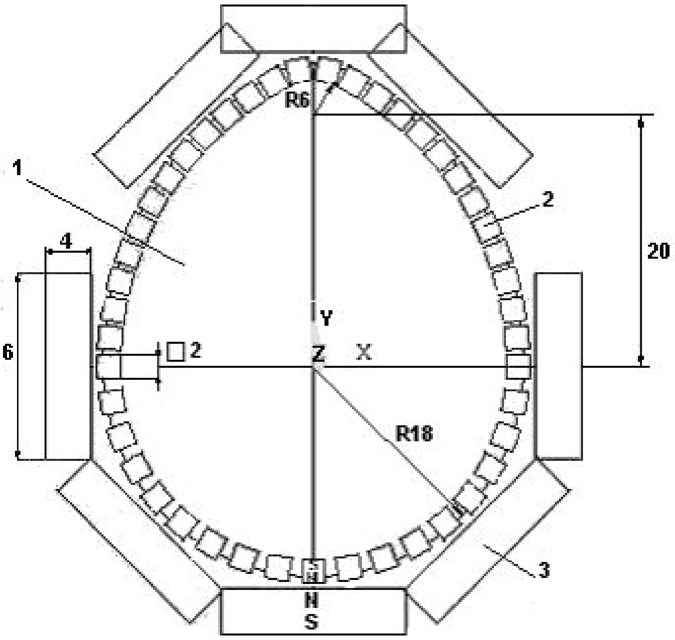
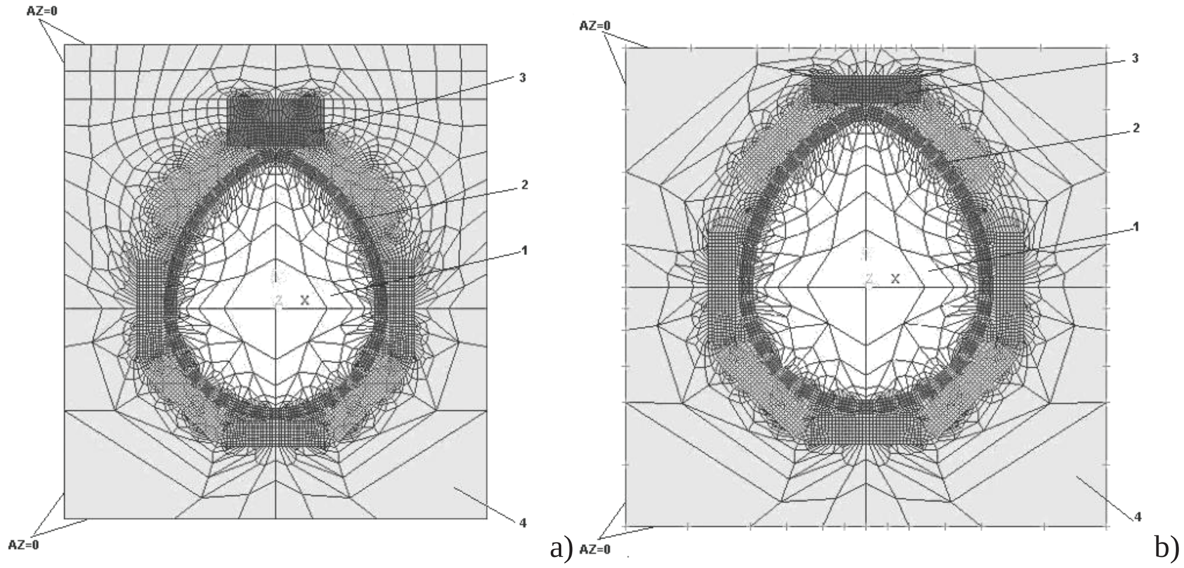


Fig. 1. The cam with a set of permanent magnets – permanent valve of valve lifter assembly. 1 – cam, 2 – permanent magnets of cam, 3 – permanent magnet of valve lifter; Z axis is perpendicular to the plane of the figure

3. Model for the set of permanent magnets

The model for the analyzed set of magnets has been elaborated with the help of FEM. The geometry of such model, for two cases for height of the valve lifter magnet 3, has been presented in the Fig. 2. To simplify calculation, the plane model has been assumed. The grid of elements has been generated automatically by commercial program ANSYS 11.0. The PLANE53 [1] element has been used, which has had eight nodes. The component AZ of magnetic vector potential, directed in Z axis, has been the degree of freedom in each node. The boundary conditions have been following. In each nodes laying on the border lines of air area the values of magnetic vector potential AZ have been equal 0. It has been assumed, that clearance between magnet surfaces has been not smaller than 0.5 mm. The permanent magnets have been Nd-B-Fe ones. Their characteristics *B(H)*, for two cases of permanent magnets material, have been presented in Fig. 3.



a) b)

Fig. 2. Geometry, grid of elements and boundary conditions for the model of set of permanent magnets. a) for magnet of valve lifter with the height equal 8 mm, b) for magnet of valve lifter with the height equal 4 mm.1 - cam area, 2 – area of magnets for cam, 3 – area of magnet for valve lifter, 4 – air area

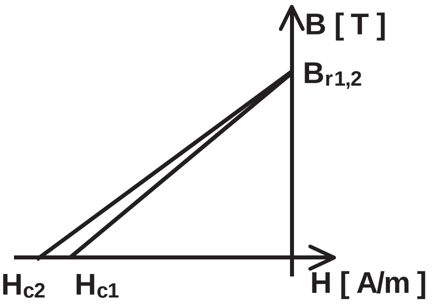


Fig. 3. The characteristics of magnetic field density B vs. magnetic field intensity H, for two cases of permanent magnet materials. Br1,2 = 1.2 T, Hc1 = -760000 A/m, Hc2 = -860000 A/m

4. The model of the seat insert – valve – valve guide assembly

The model of the seat insert – valve – valve guide assembly has been presented in the Fig. 4. Such model has been used to calculate parameters of motion for the valve. The model has been connected of the camshaft 1 with set of permanent magnets on the cam surface, valve lifter 2 with permanent magnet, valve spring 3, valve guide 4, seat insert 5 and valve 6. The boundary conditions have been following:

The valve guide and the seat insert have been fixed. The axis of the camshaft has been fixes either, but the camshaft could rotate with constant velocity. The material properties for elements of the modelled assembly have been constant. The valve and the valve lifter could move along fixed common axis. Between the valve tip and valve lifter the clearance of the desired value has been introduced. In the initial position the valve has been closed and the camshaft has been in rest. The mass of valve made of TiAl6Zr4Sn2Mo2 alloy has been equal 25.7 g [2].

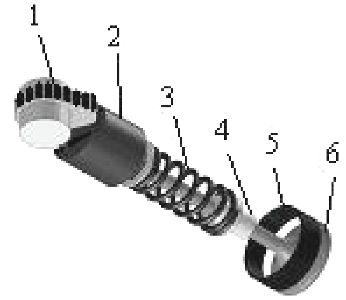


Fig. 4. The scheme of the seat insert – valve – valve guide assembly, driven by camshaft; 1 – camshaft, 2 – valve lifter with permanent magnet, 3 – valve spring, 4 – valve guide, 5 – seat insert, 6 – valve

5. The results of researches

The results of simulation have been presented in the Fig. 5, for maximum valve lift equal 8 mm and camshaft rpm equal 1000. Value of acceleration has been proportional to the value of force driving the valve. The mass of valve has been critical for such force value. For valve made of TiAl alloy the force values can be smaller about 40% than for valve made of steel [2].

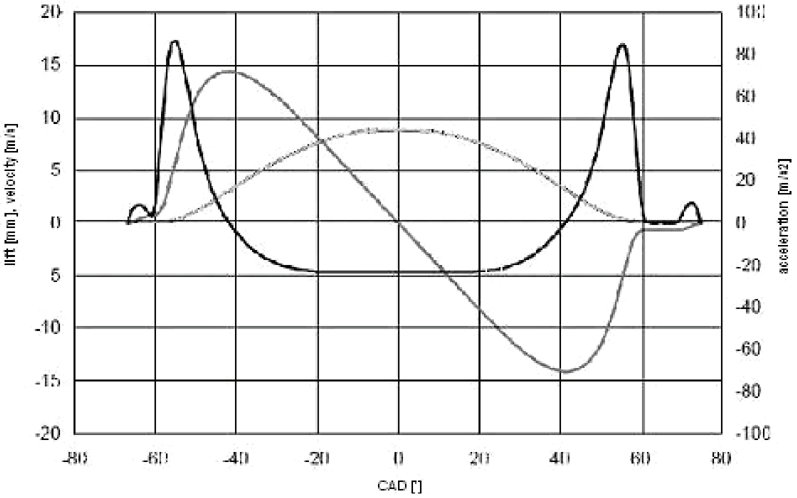
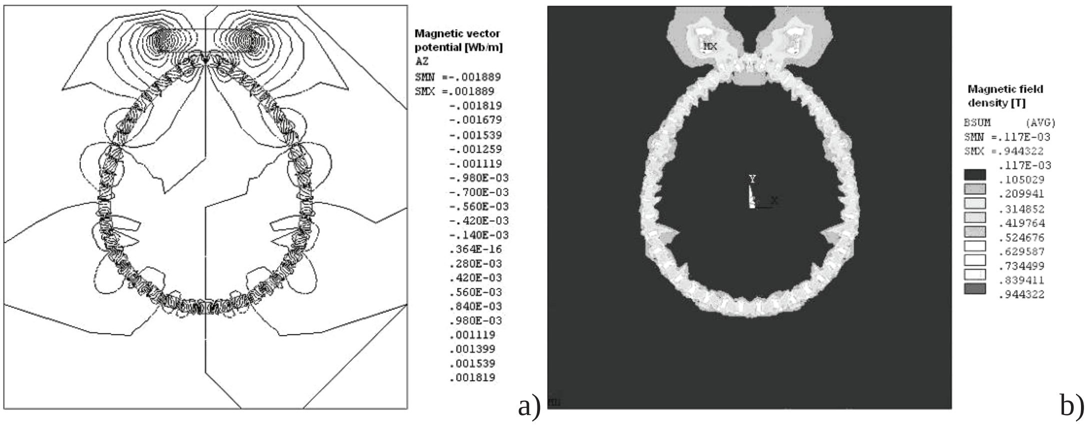


Fig. 5. Valve lift, velocity and acceleration vs. CAD (camshaft angle degree)

The results of computation for magnetic field density and for magnetic vector potential, have been presented in Fig. 6 - 11. They have been obtained for different position points of valve lifter in relation to the cam.



a) b)

Fig. 6. a) Magnetic vector potential, b) magnetic field density for position point equal 0° CAD and the magnet height of valve lifter equal 4 mm

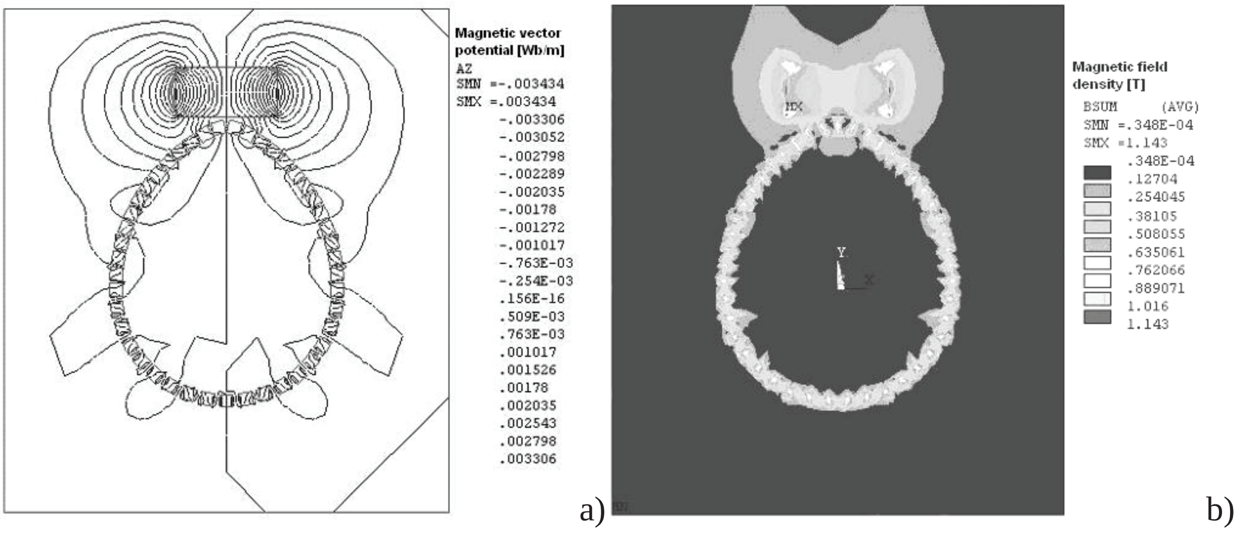


Fig. 7. a) Magnetic vector potential, b) magnetic field density for position point equal 0° CAD and the magnet height of valve lifter equal 8 mm

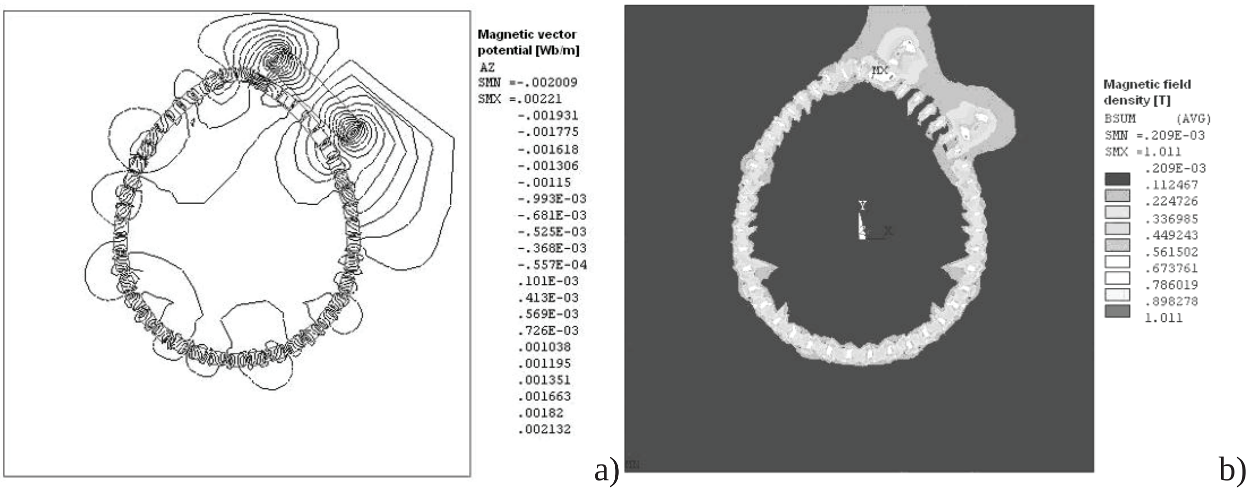


Fig. 8. a) Magnetic vector potential, b) magnetic field density for position point equal 22° CAD and the magnet height of valve lifter equal 4 mm

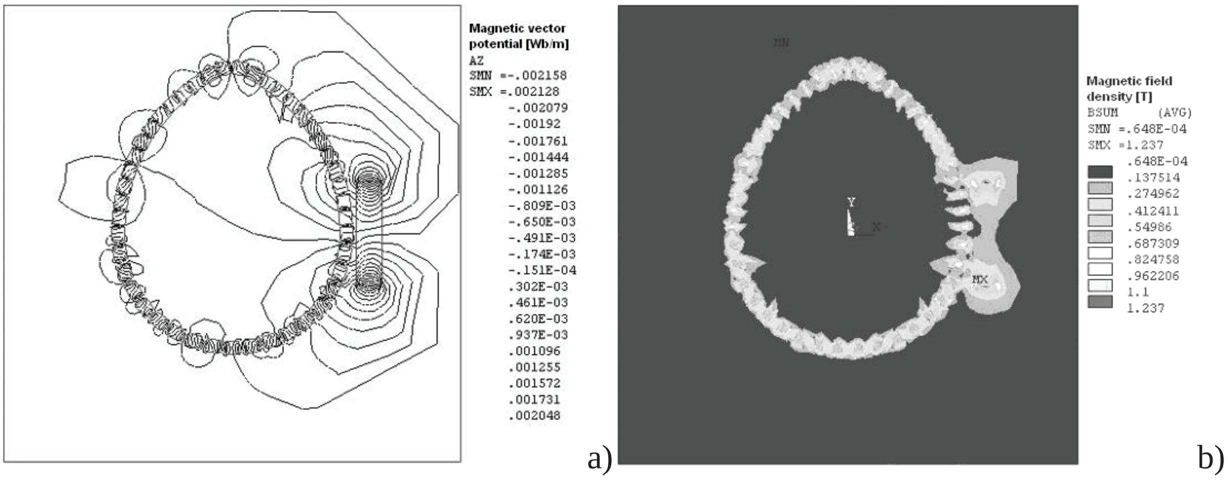


Fig. 9. a) Magnetic vector potential, b) magnetic field density for position point equal 90° CAD and the magnet height of valve lifter equal 4 mm

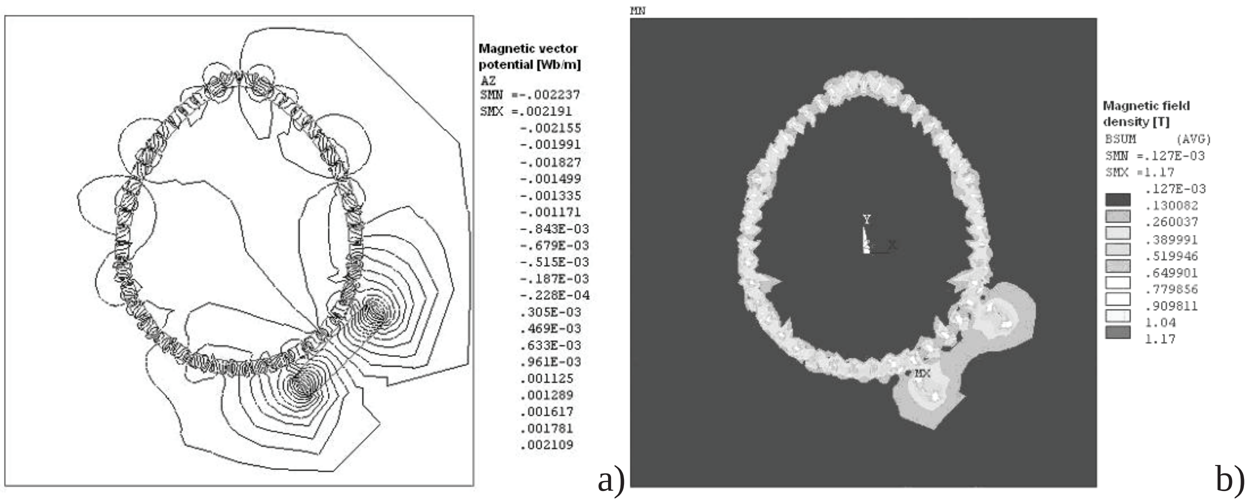


Fig. 10. a) Magnetic vector potential, b) magnetic field density for position point equal 135° CAD and the magnet height of valve lifter equal 4 mm

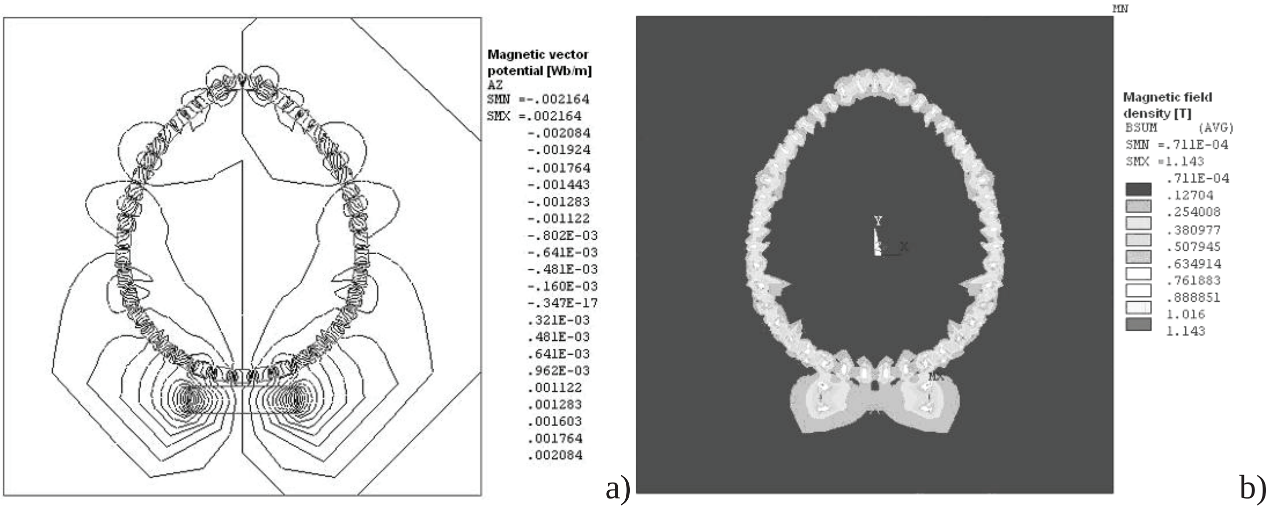


Fig. 11. a) Magnetic vector potential, b) magnetic field density for position point equal 180° CAD and the magnet height of valve lifter equal 4 mm

The magnetic field lines have been displaced from contact zone of magnets, as expected. Increasing of height of the valve lifter magnet did not improve the magnetic field influence on magnets. Lines of the field have been only displaced out stronger, without increasing magnetic forces between magnets.

Values and gradient of magnetic vector potential have been different in different position points of valve lifter in relation to the cam. Calculated values of magnetic field density have shown that the zones of magnetic saturation phenomenon can exist (Br greater than 1.4 T).

Calculated values of unit magnetic force driving the valve lifter for its different position points in relation to the cam have been presented in Fig. 12.

Values of unit magnetic force are rather small. To obtain in the position point 0° CAD the value of magnetic force equal 100 N, it is necessary to use valve lifter magnet of diameter greater than 140 mm in case of H_{c2}=860000 A/m, and greater than 150 mm in case of H_{c1}=740000 A/m. Such big diameter of valve lifter cannot be accepted for combustion engine. It can be concluded, that magnetic field forces, obtained in a set of permanent magnets, can be used only to decrease loading of the cam – valve lifter friction contact, but not to eliminate it.

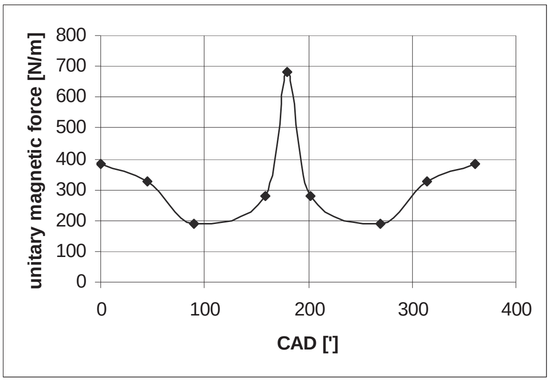


Fig. 12. Unit magnetic force driving the valve lifter vs. CAD

6. Conclusion

1. Values of force driving valve are strictly depended one mass of valve. For valve made of TiAl alloy the force values can be smaller about 40% than for one made of steel.
2. Values and gradient of magnetic vector potential are different for different position points of valve lifter in relation to the cam. The zones of magnetic saturation phenomenon can exist for material of magnet on valve lifter
3. Values of unitary magnetic force are rather small. It can be concluded, that magnetic field forces, obtained in a set of permanent magnets, can be used only to decrease loading of the cam – valve lifter friction contact, but not to eliminate it.

References

[1] *Ansys v. 11.0 documentation*.

[2] Siczek, K., *The Researches on the Tribological Properties of the Elements of the Seat Insert-Valve-Valve Guide Assembly*, Journal of KONES Powertrain and Transport, Vol. 17, No. 4, pp. 423-430, 2010.

[3] Zbierski, K., *Bezkrzywkowy magnetoelektryczny rozrząd czterosuwowego silnika spalinowego*, Monografia, Wydawnictwo Politechniki Łódzkiej, Łódź 2007.