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Numerical simulation of propagation of the MHD waves in sunspots

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Abstract. We present results of numerical 3D simulation of propagation of MHD waves in sunspots. We used two self consistent magnetohydrostatic background models of sunspots. There are two main differences between these models: (i) the topology of the magnetic field and (ii) dependence of the horizontal profile of the sound speed on depth. The model with convex shape of the magnetic field lines near the photosphere has non-zero horizorntal perturbations of the sound speed up to the depth of 7.5 Mm (deep model). In the model with concave shape of the magnetic field lines near the photosphere $\delta c/c$ is close to zero everywhere below 2 Mm (shallow model). Strong Alfven wave is generated at the wave source location in the deep model. This wave is almost unnoticeable in the shallow model. Using filtering technique we separated magnetoacoustic and magnetogravity waves. It is shown, that inside the sunspot magnetoacoustic and magnetogravity waves are not spatially separated unlike the case of the horizontally uniform background model. The sunspot causes anisotropy of the amplitude distribution along the wavefront and changes the shape of the wavefront. The amplitude of the waves is reduced inside the sunspot. This effect is stronger for the magnetogravity waves than for magnetoacoustic waves. The shape of the wavefront of the magnetogravity waves is distorted stronger as well. The deep model causes bigger anisotropy for both mgnetoacoustic and magneto gravity waves than the shallow model.

Keywords. helioseismology, magnetic fields, sunspots

We performed simulations for two types of magnetohydrostatic models of sunspots referred to as "deep" and "shallow" models with grid size $376 \times 376 \times 67$ ($\Delta x = \Delta y = 0.15$ Mm, $\Delta z_{top} = 0.05$ Mm, $\Delta z_{bottom} = 0.52$ Mm) for different strength of the magnetic field at the photospheric level (0.84 kG, 1.4 kG, and 2.2 kG).

The wave amplitude decreases when the wave enters the sunspot and restores its value when the wave passes the center of the sunspot. For the source distance of 9 Mm the wave amplitude inside the sunspot becomes bigger than outside. For the source distance of 12 Mm the wave amplitude inside the sunspot remains smaller than outside for all moments of time. For the fixed source location the wave amplitude inside the sunspot grows with the strength of the magnetic field.

For simulations with the magnetic field and multiple sources randomly distributed at the depth of 0.1 Mm the ratio of oscillation amplitudes outside and inside the sunspot increases to 4.9 ± 2 in comparison with the non-magnetic simulations 2.3 ± 0.4. The source strength was reduced inside the sunspot to simulate the suppression of the acoustic sources by the magnetic field inside sunspots. Observed ratio is 3.0-4.5 (± 0.4). This can be an evidence, that not all sources are suppressed inside the sunspot umbra.