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FRICTION AND STICK-SLIP IN A TELESCOPE CONSTRUCTION*

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Summary

Stick-slip in high resolution telescopes should be avoided. The contact places where stick-slip can occur are described. Some contact places require a high friction coefficient, others a low friction coefficient. Some experiments have been carried out to find lubricants for contact places which combine no stick-slip with high or low friction coefficient.

1. Introduction

Fluctuations in the air temperature in the direct neighbourhood of a telescope deteriorate the image quality. In the case of solar observations, these fluctuations are strongly generated by the heating of the ground in the sunlight. Wind will mix the air. Measurements of the temperature fluctuations showed that a wind breeze of 5 - 10 m s^{-1} gives a rather homogeneous air temperature above a height of 15 m in the case of a flat ground surface. The solar telescope which is under construction will try to use the favourable seeing conditions which are brought about by the wind. The telescope incorporates a tower support of 15 m height, which puts the optical instrument in the air where the temperature is homogeneous as illustrated in Fig. 1. The tower and telescope themselves should not disturb the air mass temperature around the telescope. To that end, the tower and as far as possible the telescope consist of an open steel framework, which is transparent to the wind. The framework is of a special stiff construction because the vibrations of the image due to mechanical vibrations in the telescope induced by the wind must be smaller than the optical resolution of 0.25 seconds of arc of the telescope. The construction is easily mounted and dismounted because of the applied screw connections. Hence the telescope is removable and several sites can be tested for their image quality.

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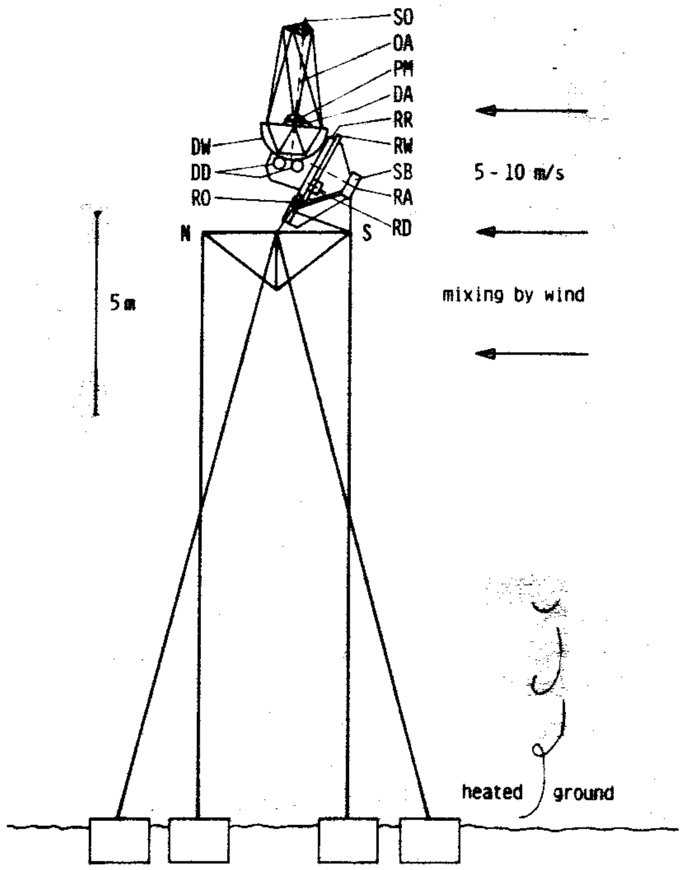

Fig. 1. **Solar telescope and tower, consisting of an open steel framework:** OA, optical axis; PM, primary mirror; SO, secondary optics; DA, declination axis (perpendicular to the paper surface) formed by two spherical roller bearings; DW, declination gear wheel; DD, declination drives; RA, right ascension axis formed by a spherical roller bearing (SB) and a roller raceway (RR), which is supported by two rollers (RO) with spherical roller bearings mounted in the base frame on the tower platform oriented from north (N) to south (S); RW, right ascension gear wheel; RD, right ascension drives.

2. Stick–slip

Friction in connection with stick–slip effects is important to three types of elements in the telescope construction.

(1) Screws connect the parts of the steel framework. The connections are based on the friction between the parts under the preload of the tightened screws. Temperature differences between the framework parts and in addition differences in the expansion coefficients due to the use of different materials cause small shifts between the parts. The parts should shift gradually without jerks larger than 1 μm. Jerks would cause image motion, which would deteriorate the image quality. Gradual motion can be compensated by the image-guiding system which follows the rim of the sun. What we need is a material, a paste, between the sliding surfaces with a high coefficient of friction for transfer of the forces caused by gravity and windload but without stick–slip if, owing to differential thermal expansions, the forces exceed

the friction forces. The forces caused by differential thermal expansion are high because of the stiff construction using framework members with large cross-sectional areas.

(2) Spherical roller bearings are applied in the declination and right ascension axis: see Fig. 1. These bearings permit self-aligning by sliding of the rollers in the spherical contour of the outer raceway. In this way, deformations of the framework by differential thermal expansions will never cause jamming and high loads in the bearings. However, stick–slip effects can arise in the slow self-aligning motion. A lubricant, a grease, is needed which avoids stick–slip effects larger than 1 μm in the bearings; this lubricant now needs to have a low coefficient of friction and not a high coefficient of friction as in the previous case. Also, the lubricant should not deteriorate the smooth rotation of the rollers on the raceways. This rotation is also very slow and can produce stick–slip effects. The right ascension axis turns once in 24 h, the declination axis making only small correcting motions to keep the image in its place. The correcting motions compensate among other things the deformations of the framework.

(3) The right ascension axis and declination axis are driven by involute cylindrical spur gears: see Fig. 1. The slow motion of these gears also shows the danger of stick–slip effects, which in this case are caused by the friction between the teeth, and here also sudden motions of more than 1 μm are harmful to the image. The drives are of a special stiff design, which minimizes the amplitude of stick–slip jerks. Nevertheless, a lubricant suppressing stick–slip and with a low coefficient of friction is desirable, as in case 2. A difference with the previous case is that here are no rolling elements.

3. Experiments

We carried out some simple experiments with diverse commercially available materials such as pastes, greases, oils and bonded lubricants. We tightened screws which pressed together a pair of large disk springs. Hence the screws had a long way to turn under a high load. We put the material to be tested under the head of the screws. The screws and the rings under the screw heads were of steel grades similar to the parts of the framework and the gears: quenched and tempered steel. The screws were tightened with torque wrenches. Long handles on the wrenches made slow and gradual rotation by hand easy. The compression of the disk springs was measured with the help of a dial gauge with a scale unit of 1 μm. The force on the screw head is calculated from the compression. The coefficient of friction follows from the force, the torque and the mean diameter of the ring-shaped contact surface between screw head and ring.

For case 1 we selected a paste intended for threaded fasteners. One of the components is probably copper powder. We measured friction coefficients between 0.133 and 0.188, the lower values being obtained for lower pressures: 0.133 - 0.160 in the pressure region 70 - 340 N mm^{-2} and 0.142 -

0.188 in the higher pressure region of 340 - 560 N mm^{-2}. We could not observe any stick–slip effect.

For cases 2 and 3 we compared mineral oil, ball-bearing grease, ball-bearing greases with extreme-pressure additives, pastes with molybdenum disulphide and polytetrafluoroethylene (PTFE (Teflon)) sprays. The best results were found with the molybdenum disulphide paste: no observable stick–slip and the lowest friction coefficients of between 0.111 and 0.072. Frequent tightening and loosening of the screw reduces the friction coefficient: 0.072 was reached after tightening five times. No stick–slip was observed with the molybdenum disulphide pastes and PTFE sprays. However, after frequent tightening seizure can occur with PTFE sprays. Mineral oil and ball-bearing greases, as well as the grades with extreme-pressure additives (but without molybdenum disulphide), clearly showed stick–slip effects observable by jerks in the rotation of the wrenches, by unsteady motion of the dial gauge and by noise (cracks).

4. Conclusion

We plan to apply the paste for threaded fasteners between the contact surfaces in the framework connections described in case 1.

For the cases 2 and 3 we plan to treat the surfaces of the teeth and the spherical contours of the outer raceways of the spherical roller bearings with the molybdenum disulphide paste, to remove the excess paste and to lubricate with a grease containing molybdenum disulphide. The manufacturer of the spherical roller bearings warned us that excess molybdenum disulphide paste can be harmful to the bearings. It is unclear whether this harm can occur for the very low velocities in this case.

For the described cases the manufacturers of lubricants and bearings did not have experience with stick–slip effects in the micrometre region. Experience with stick–slip only exists with oil for guideways in machine tools. This oil combines an absence of stick–slip with low friction for low and moderate pressures. High friction is required in case 1 and the pressures in the contact lines of the bearings and gears are high in the cases 2 and 3.

We would welcome any information which enlarges our insight into micrometre-sized stick–slip effects and request anyone who has experience in this field to contact us.