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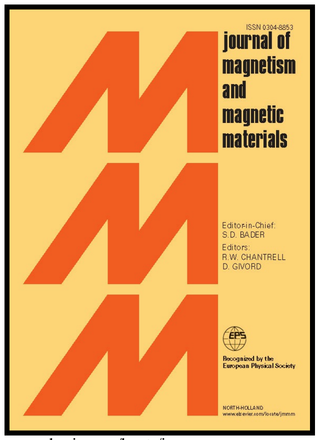

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A ferrofluid based artificial tactile sensor with magnetic field control

T.I. Volkova[a,*], V. Böhm[a], V.A. Naletova[b], T. Kaufhold[a], F. Becker[a], I. Zeidis[a], K. Zimmermann[a]

[a]*Technical Mechanics Group, Faculty of Mechanical Engineering, Technische Universität Ilmenau, D-98684 Ilmenau, Germany*
[b]*Faculty of Mechanics and Mathematics, Lomonosov Moscow State University, 119991 Moscow, Russia*

Abstract

The paper deals with a tactile sensor inspired by biological hairs of mammals. The working principle is based on the effect of the magnetic force exerted on a paramagnetic body submerged into a ferrofluid volume under the influence of a nonuniform magnetic field. The deflection of the sensor's rod caused by external mechanical stimuli may be unambiguously identified by the distortion of the magnetic field, which occurs due to the motion of the attached body in the ferrofluid. The magnetic force acting on the body is evaluated experimentally and theoretically for the nonuniform magnetic field of a permanent magnet. The controlled oscillations of the rod are realised by applying a nonuniform magnetic field of periodically altering direction.

Keywords: Tactile sensor, Ferrofluid, Magnetic force, Vibrissa, Controlled oscillation

1. Introduction

This paper presents a concept of an artificial tactile sensor inspired by special biological hairs of mammals with the working principle based on the magnetic properties of a ferrofluid (FF) in applied magnetic fields. These thin long hairs, called vibrissae or whiskers, grow usually in groups in different locations on an animal's body. Among the most familiar to us are mystacial vibrissae orderly distributed over the whiskerpad on a muzzle, supraorbital vibrissae above the eyes, and carpal vibrissae that are located on the downside aspect of the forelimbs. For all terrestrial and marine mammals except humans, vibrissae are significantly important tactile sensors used for the exploration of the surrounding area, texture discrimination, or even detection of water vibrations [1, 2, 3]. In contrast to other types of body hairs, the vibrissal follicle, known as the follicle-sinus complex, incorporates lots of sensory nerve endings and a capsule of blood. It is also surrounded by specialised muscles that allow whisking oscillations of the vibrissa in bouts of variable duration [4].

This fascinating biological paradigm has motivated the engineers to design various tactile sensors and find possible applications for them, since it promises to be competitive with an artificial vision. Some examples are the biomimetic whisker with an attached permanent magnet and Hall-effect sensors, which measure the difference of magnetic flux caused by the movement of the flexible whisker [5], and the whisker transducer consisting of a slender steel wire and a cantilevered piezoelectric bimorph for simultaneous actuation and sensing [6]. In [7, 8], an electroactive polymer is used to design prototypes of active whisker systems. However, one of the keys to the implementation of such sensors, according to the biological idea, is the realisation of the viscoelastic support of the hair, as it is embedded inside the follicle and circled by the blood capsule.

In the present work, an approach to the design of a tactile sensor as a rigid rod with an attached body, which is submerged into a volume filled with a viscous FF, is proposed. Due to its structure, the FF combines such properties as fluidity and viscosity with properties of superparamagnets. In [9, 10, 11, 12], it is shown that there is a magnetic force exerted on a paramagnetic body immersed in an FF volume under the influence of an applied magnetic field. The idea of the work is to use this effect to realise controlled oscillations of the artificial vibrissa, i.e. active "whisking" movements. External mechanical stimuli arising from a contact of the rod with an investigated object can be detected based on the measurement of the consequent magnetic field distortion. Moreover, the proposed approach may provide the variability of viscoelastic properties of the support, since the FF reacts to an external magnetic field by the change of viscosity [13].

The theoretical investigations made in [14] show that the three-dimensional oscillations of the spherical body inside the spherical FF volume can be controlled by means of the direction of a uniform applied magnetic field. In this case, however, the effect is rather small, since the magnetic force occurs due to the difference in magnetic properties between the body material, the FF and a surrounding medium. For a nonuniform magnetic field, the force depends on the direction and the magnitude of the field gradient, and hence it may be significant.

For the past decades, the described effect of the magnetic force acting on paramagnetic bodies and the related effect of the levitation of permanent magnets inside an FF volume have been used in various applications such as magnetic fluid separators [15], polishing devices [16], and vibration dampers [17].

*Corresponding author
Email addresses: tatiana.volkova@tu-ilmenau.de (T.I. Volkova), valter.boehm@tu-ilmenau.de (V. Böhm), naletova@imec.msu.ru (V.A. Naletova), tobias.kaufhold@tu-ilmenau.de (T. Kaufhold), felix.becker@tu-ilmenau.de (F. Becker), igor.zeidis@tu-ilmenau.de (I. Zeidis), klaus.zimmermann@tu-ilmenau.de (K. Zimmermann)