"Questionnaire Exemption Request No. 2013-4"
Response from Moog Components Group

General comment

There are some sliding technologies that are available that were not addressed in the exemption request—most notably fiber brush technology. Fiber brush products feature a brush design composed of multiple small "fibers", or wires, culminated into a bundle that provide intimate ring contact, low brush force, low torque, and excellent conductive properties. The multiple fingers allow low contact force and subsequently low friction and very low wear rate. The multiple contacts also provide good current density properties for high current. These contacts are well suited for low noise and high current hybrid applications. Evaluation of this technology is certainly warranted in intravascular ultrasound imaging and fiber brushes are actually being used in similar applications.

The vendor of the mercury slip ring solution only produces mercury-wetted contacts and many of the arguments against metal contacts seems to come from this vendor's natural bias ("Based on conversations with the slip ring manufacturer . . . solid metal to metal contacts would not meet the performance required. . . (6e) ").

Questions

1. The information provided by the applicant addresses the need of an exemption for mercury in high speed rotating electrical connectors (slip rings) used in high operating frequency intravascular ultrasound imaging systems.

a. Please state if the requested exemption is relevant for additional applications that are required to abide to the RoHS substance restrictions stipulated in Article 4(1).

RESPONSE: Sliding contact (precious metal on precious metal) slip ring technology is available that abide with ROHS restrictions that offer low noise and acceptable high operating frequency in the operational range of 40 – 60 MHz. Slip rings with this technology are used in many commercial, industrial and defense applications requiring low noise, long life, and high power.

b. If so, please provide information to demonstrate why such an exemption would be justified according to the Article 5(1)(a) criteria.

2. From the information submitted, the applicant is not aware of possible substitutes or developments that may allow for substitution or elimination.

a. Please provide information concerning possible substitutes or developments that may enable reduction, substitution or elimination, at present or in the future, of mercury in high speed rotating electrical connectors (slip rings) used in high operating frequency intravascular ultrasound imaging systems.

RESPONSE: Fiber brush technology was developed in the early 1980's for space applications to eliminate the issues in solar array drives for lubrication, wear debris generation and outgassing in traditional sliding monofilament wire and silver graphite sliding contacts. This fiber brush contact technology has since evolved into a broad range of applications including military, medical and industrial

applications. Advantageous features of this technology are very low electrical noise, excellent conductivity, and very long life. There are a number of claims made in the exemption that are stated as fact that are just assumptions.

1. *Non-mercury wetted slip rings generate in-band radio frequency noise as the precious metal fingers vibrate against the drum during rotation* or as stated elsewhere *the RF noise generated by typical metal on metal slip rings as the metal contacts vibrate under rotation*. A recent investigation presented at the IEEE Holm Conference on Electrical Contacts (Dorsey, Coleman et al. 2012) showed that the high frequency components of slip ring noise are actually quite low. There are several non-linear (non-ohmic) effects that are present in theory but represent negligible effects (especially in the frequency range in question). This notion that any sliding contacts and specifically fiber brush sliding contacts generate RF noise during rotation is just wrong. Some sliding contacts (especially single wiper contacts) can generate low frequency noise with rotation, but the frequency seldom exceeds 10 kHz.
2. *The conductive liquid Mercury within the slip ring provides for lower friction than any solid-to-solid contact.* Without an actual specification to which to compare the fiber brush technology it is only possible to address this general assumption in anything but the broadest terms. The low contact force of the fiber brush design provides a very low friction force. Compared to the viscous drag of mercury at 1900 RPM within the mercury channel including the channel-to-channel isolators, the frictional drag of the fiber brushes should be fairly close if not less. The sealing forces from a *completely sealed housing* will overshadow the friction of the electrical contacts (either mercury or fiber).
3. *Furthermore, non-mercury wetted slip rings are not rated to the high peak power of the ACIST HD-IVUS system and fail within minutes*. The 4 amp rating specified in paragraph 7 of the 1st Questionaire Exemption Request No. 2013-4 is not a difficult requirement for fiber brushes. **Properly designed electrical contacts do not fail within minutes**. Typical miniature fiber brush life is 100+Million revolutions. However, any electrical contacts that are mis-applied or poorly designed can fail within minutes.
4. *There is negligible risk of mercury emissions that apply to the component at end of life*. Since the wetted mercury slip ring is a rotating device, the mercury must be sealed from the atmosphere with a sliding or rotary seal of some design. Any engineer that considers the risk of leakage with a rotary seal as "negligible" is underestimating the risk. Although the manufacturer's information of 2 billion cycles of life is interesting, it would be useful to see a more rigorous reliability analysis of mean time between failure (MTBF) as well as a failure modes analysis (FMA) to truly understand the risk of mercury exposure to the patient. Some finite number of these units will fail and "negligible" does not seem to be an adequate analysis.
5. *Wide bandwidth of mercury wetted slip rings*. The bandwidth of slip rings (mercury wetted or contacting) is a function of geometry and design, and this operational bandwidth is primarily a function of diameter and lead termination design. Path length variation with rotation creates electrical wavelength variation leading to standing waves and insertion loss. This has nothing to do with the contact design and mercury wetted slip rings are constrained by the same rules of physics as metal contacting slip rings. Again, a properly designed metal contacting slip ring of a certain diameter **will have the same** RF characteristics as a mercury wetted slip ring.
6. *Noise from a non-mercury wetted slip ring is reasonably anticipated to be in the range of tens to hundreds of millivolts (¶ 6a)*. Statements such as this should be supported by test data. From the discussion it is apparent that low noise within the bandwidths of 40-60 MHz is critical. The most significant contribution to noise in this bandwidth from both metal contacting and mercury wetted slip rings is phase noise from path length variations with rotation rather than

contact noise. It is not to be "reasonably anticipated" that a properly designed metal contact cannot meet a low noise requirement within the 40-60 MHz bandwidth.

7. *In non-mercury wetted slip rings the noise performance is presumably more degraded at high rotation speeds because friction effects leading to noise are worsened at high rotation speeds.* The presumption in this case is not correct. In fact the coefficient of friction is typically inversely proportional to the rotational speed. There can be some relationship between noise and rotational speed, but it is certainly more complex than this statement implies and it is just as often worse at low rotational speeds than high. But as discussed in 5 and 6, the RF noise is dependent more on geometry than contact physics.

b. Please indicate if the negative environmental, health and/or consumer safety impacts caused by substitution are likely to outweigh the environmental, health and/or consumer safety benefits. If existing, please refer to relevant studies on negative impacts caused by substitution.

RESPONSE: No negative environmental, health and/or consumer safety impacts are caused by fiber brush technology

3. The applicant has proposed the following wording for this exemption:

"Mercury components used in high operating frequency (>50MHz) Intravascular Ultrasound Imaging Systems"

As the applicant has indicated that the relevant application falls under the scope of Annex I Category 8 (medical devices), should an exemption be granted it is to be added to Annex IV of the RoHS directive.

a. Do you agree with the scope of the exemption as proposed by the applicant? Please suggest an alternative wording and explain your proposal, if you do not agree with the proposed exemption wording.

RESPONSE: No we do not.

1. The risk posed by mercury sealed from the environment by a rotating seal is significantly greater than "negligible " A more rigorous reliability analysis should be produced.
2. There are long life, low wear contact technologies available that should be evaluated.
3. The sweeping generalizations presented in this exemption request indicate a lack of rigor in evaluation of alternatives.

b. Please state whether you either support the applicant's request or whether you would like to provide argumentation against the applicant's request. In both cases provide detailed technical argumentation / evidence in line with the criteria in Art. 5 (1) (a) to support your statement.

RESPONSE:

No, we do not support the request.

Fiber brush slip rings feature a brush design composed of multiple small "fibers", or noble metal wires, formed into a bundle that provide intimate ring contact, low brush force, low torque, and good conductive properties. The multiple fingers allow low contact force and subsequently low friction and very low wear rate. The multiple contacts also provide good current density properties for high current. These contacts are well suited for low noise and high current hybrid applications. Proper design of the

slip ring can address the 40-60 MHz bandwidth noise issue, by minimizing signal path variation and subsequent phase noise. Evaluation of this technology is certainly warranted in intravascular ultrasound imaging. Fiber brushes are actually being used in similar applications.

REFERENCE

Dorsey, G., et al. (2012). High Speed Data Across Sliding Electrical Contacts. Proceedings 59th IEEE Holm Conference, Portland Or.