Design Requirements and Solutions for Modern Radar Rotary Joints

A. Doleschel, H.-U. Nickel and T. Gebauer
Spinner GmbH, Aiblinger Str. 30, 83620 Westerham, GERMANY
andreas.doleschel@spinner-group.com

Abstract:
Rotary joints consist of several types of transmission channels such as radio frequency, power, media and data channels. All these channels do have their own properties which need to be respected in the mechanical layout of a rotary joint system. Additionally operational (e.g. maintenance), environmental, and legal requirements do influence the design parameters which are discussed in this paper.

Key words: Rotary joints, design principles, maintenance

I. INTRODUCTION

Surveillance radars employ multichannel rotary joints as transition gears between the transmit/receive equipment and a directional antenna that is rotating around its azimuth. The task of the rotary joint is to enable low-loss transmission channels between stator and rotor for various electrical and optical signals and also for electrical power and media, if necessary. Transmission channels can be divided into four different types according to their primary function:

- Radio-frequency (RF) channels (high and low power signals)
- Power channels (for power supply of electrical equipment)
- Media channels (cooling media, dry air, …)
- Data channels (optical, Ethernet, RS232, RS422, …)

Apart from these functional aspects some other aims are addressed during the design of a rotary joint:

- Reduced development times to be reactive on new radar systems
- Reduction of maintenance periods and tasks, but in parallel increased reliability
- Requirements for environmental aspects such as ambient temperature, humidity, operating altitude, or even transport situations
- Legal requirements as e.g. safety aspects

II. MODULAR SYSTEMS

Multichannel rotary joints are composed of a number of individual modules that usually represent a single transmission channel. In the following sections we illustrate the design of some basic modules. In general the modules are characterized by two features:

- hollow-shaft-design i.e. a rotor with a center opening that enables cables or pipes of neighboring modules to be fed through;
- coupling mechanism e.g. clutch dogs that allow for a torsional rigid connection of two adjoining modules.

Both features are illustrated particularly distinct in Fig. 1. This design principle is usable for all kinds of RF, media, and data modules.

1 Radio frequency medium power module with coaxial cables

Fig. 1 shows an L-band medium power channel with a relatively large center opening (frequency range 1.0 to 1.1 GHz; average power rating 500 W; typical insertion loss 0.5 dB; clear diameter 70 mm). This module is a universal building block for secondary radar applications.

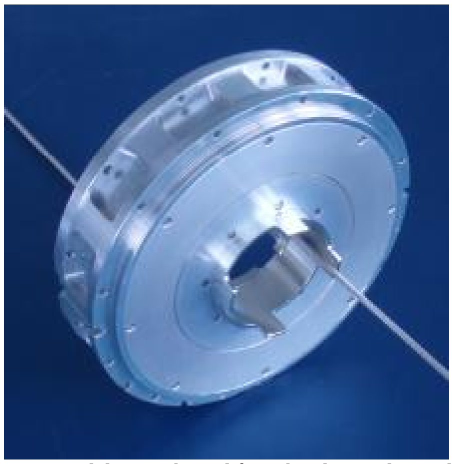

Figure 1 Modular RF channel for L-band secondary radar

2 Radio frequency high power waveguide module

Most waveguide channels use the classical design approach described in [1] where a contactless coaxial rotary joint is extended on both sides by a coax-to-waveguide transition of the door-knob type. Being equipped with a concentric hole the center conductor of the coaxial line section represents the necessary hollow shaft. Fig. 2 shows an S-band waveguide channel that follows that approach. The module is employed in weather radars (waveguide R32; frequency range 2.7 to 3.0 GHz; peak power rating 1 MW; typical insertion loss 0.1 dB; closer details of the design are given in [2]). In order to prevent arcing during operation at high peak powers the waveguide transition exhibits very smooth walls and carefully rounded edges (Fig. 3). An additional provision to allow for high peak powers is to pressurize the waveguide with dry air or with SF_6.

Figure 2   RF waveguide channel for high power operation at S-band

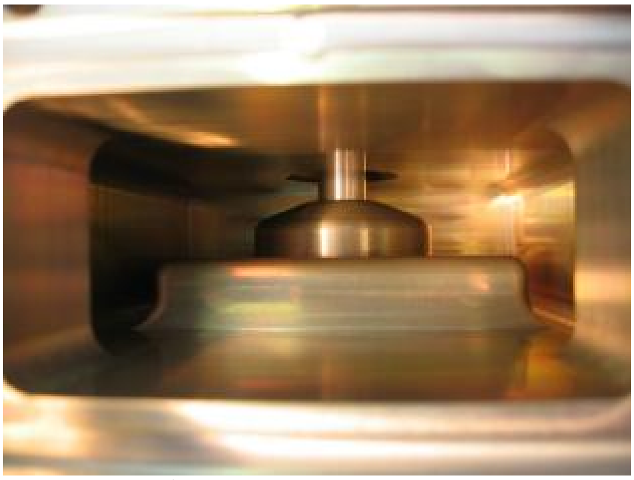

Figure 3   Details of door-knob type transition exhibiting the hollow center conductor

3   Fiber-optic multichannel module

Contactless fiber-optic rotary joints with more than one transmission channel are used wherever several analog or digital optical signals need to be transmitted independently. A longitudinal section of a typical multichannel module is shown in Fig. 4. As described in [3] the idea behind this design is an optical imaging which projects a stationary onto a rotating array of collimated fiber ends. The necessary de-rotation is provided by a Dove prism that is driven by a differential gear at half the relative rotating speed of rotor and stator. In particular the Dove prism is integrated in a shaft which is coupled by a bevel gear to the rotor on the one hand and to the stator on the other. This basic concept is employed for both multimode and single-mode optical fibers.

Fig. 5 shows the photograph of an exemplary module equipped with twelve single-mode channels. Its basic specification is: fiber type E9/125; wavelengths 1310 nm and 1550 nm; insertion loss ≤3.5 dB; return loss ≥50 dB; channel isolation ≥50 dB; body diameter 60 mm. In contrast to the other modules presented here this design does not provide a hollow shaft.

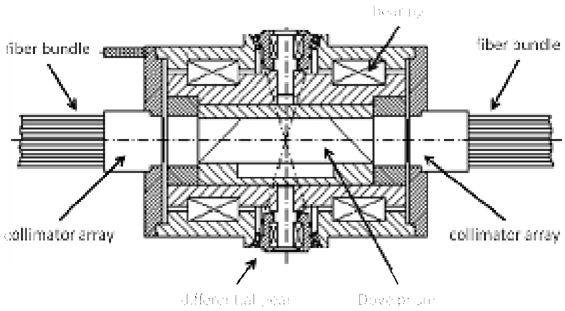

Figure 4   Fiber-optic multichannel module, longitudinal section

Figure 5   12 channel FORJ module with input and output fibers

4   Gigabit Ethernet module

A newly developed module for contactless bidirectional data transmission with Ethernet interface is shown in Fig. 6 (standards supported: 10BASE-T, 100BASE-TX, 1000BASE-T; clear diameter 16 mm). This module automatically recognizes and selects the connected devices’ current Ethernet standard and duplex mode (full or half). Modules of this kind with different clear diameters are standard building blocks for today’s and future’s multichannel rotary joints. All Ethernet modules can be stacked directly and will be attached together to an Ethernet unit which can be implemented into a rotary joint assembly.

Figure 6   View on a Gigabit single module.

Typically the electronics located on the rotary and stationary part do need a power supply which is normally provided by additional slip ring ways.

5 Media rotary joint

The list of necessary transmission channels is completed by the media rotary joint. In general two different media need to be supported on a rotating radar antenna. Dry air needs to be transferred in order to prevent electrical arcing or excess insertion loss in radio frequency areas. Dry air is usually already transmitted by the high power radio frequency channel, if exists.

Modern radar antennas do generate the RF power directly on the rotating part. This process calls for a cooling liquid which needs to be transmitted up and down. In total 3 media channels (1x dry air, 2x cooling media) need to be designed for a typical modern system rotary joint.

Figure 7 Schematic view on a media rotary joint

In Fig. 7 a two channel media module is shown in a test bench. This module with a media pressure of 8 bars and a flow rate of 30 liters/minute has passed 5 mio revolutions without leakage. The special design is supporting the bench purpose, for a real radar system installation the two channels would directly be attached together eliminating the in-between back flow channels (small feeds).

III. RELIABILITY AND MAINTENANCE

A typical maintenance schedule consists of regular checks (e.g. yearly) against corrosion, external wear or other damages which can be observed from outside.

Further checks can only be processed in a workman's area (depot-level check); due to the complexity of a multichannel rotary joint it is mostly performed at the manufacturer's site. Due to the high effort it is desired to enlarge the period between these maintenance checks as far as possible.

Regularly, during depot-level checks the following parts need to be replaced or reworked:

1 Dynamic Seals

Seals inside rotary joint systems are installed for several reasons:

a) Prevention for external particles/water to fulfill a specified IP class.
b) To prevent air leakage of high power RF channels or dedicated air transmission channels with only 0.2 bar operational differential peak pressure.
c) Seals of media joints designed for a high differential pressure up to 20 bars peak pressure.

As in cases "a" and "b" the seal runs more or less dry, a dedicated wear rate is unavoidable. But, as no (in case "a") or only a slight differential pressure (in case "b") occurs, only low preloading forces are needed, the wear rate is relatively low. Over the life time of such a seal, the wear is degrading the seal function. This degradation normally follows a bath tube curve, in the beginning the wear rate is relatively high but decreases to a minimum. During that period (run-in) the function of the seal is still improving to a minimum leak rate. With more and more revolutions the wear rate and the leak rate will increase again. Typically some 20 mio revolutions can be reached, however this depends strongly on the type of seal and the preloading of the seal.

For the increasing number of rotary joints with media channels the seals for these media channels are also a key component. A leak rate is practically not avoidable, thus an acceptable leak rate needs to be defined respecting the complete specified temperature range. Due to the high wear rate of such contacting systems also non contacting gap seals can be used. These gap seals have two main advantages, the turning torque is drastically reduced and the wear is practically eliminated. On the other hand, high manufacturing accuracy and low running tolerances are increasing the manufacturing costs.

2 Dynamic electrical contacts

In case a contacting system (e.g. contacting RF or slip ring unit) is included (necessary for power transfer, electrical signals, and/or low frequency signals) a major task consists of the re-oiling of the slip ring units or even an overhaul at the manufacturer site. As nature of the contacting system, wear is not avoidable and thus the quality of the signal transfer is degrading over usage. In some cases it is tolerable by the radar systems, but at a certain level it is not any more acceptable. In some cases slip ring units did run up to 100 mio revolutions without maintenance with gold contacts but such a high life time strongly depends on the environment (dust, vibration, salt, humidity) and cannot be guaranteed by the manufacturer. Normally a service interval is limited to 10 mio cycles, however for dedicated systems in controlled environment the interval can be enlarged to 25 or 40 mio revolutions.

3 Bearings

The bearings life is determined by the type and presence of a lubricant. Due to the design the bearing forces are negligible, thus the calculated life time with classical bearing calculation tools is several times the desired life time of the rotary joint. The lubricant has to be relatively robust against RF influence, needs to be usable during the complete temperature range and should keep its performance for several years of usage. The use of a special lubricant ensures this requirement, however in case of a major overhaul the main bearings are normally replaced as the unit is being delivered back to the customer with the expectation to run again without failure for the next maintenance period.

IV. FUTURE MAINTENANCE CONCEPTS

The life time of a rotary joint is normally limited by the mechanical wear of the sliding contacts. In order to reach the aim of reduced maintenance and increased reliability of a rotary joint, it is necessary to reduce the number of sliding contacts. Depending on the chosen geometry, material, lubrication, and contact pressure the wear is more or less propagating during operation. To eliminate wear completely contactless systems need to be used. Contactless systems are available for RF channels (choke systems with limited bandwidth), for data channels (Ethernet and optical joints), for media, and for some power transmission in the range up to 1 kW.

Only for the transmission of high power, slip ring units with sliding contacts are still necessary. However due to graphite technology several 100 millions of revolutions can be achieved. Using such technologies only the wear in these power slip rings and in mechanical parts as bearings, dynamic seals, or gears (e.g. of optical joints) are internal reasons for maintenance tasks. Of course, depending on the environment of the rotary joint also additional maintenance tasks are necessary (e.g. use in very corrosive or humid environment).

An example of such a system with already reduced contacting systems is the following multichannel rotary joint (Fig. 8).

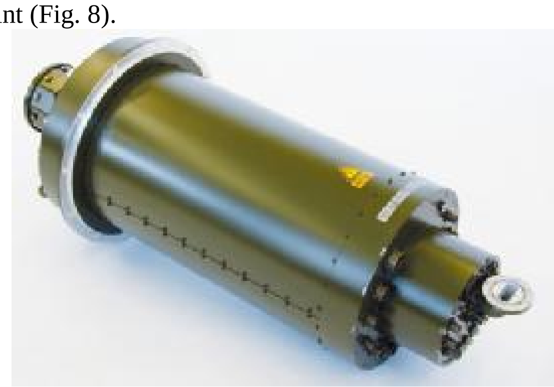

Figure 8 Multichannel rotary joint

This multichannel rotary joint is used for a radar employing a passive electronically scanned array (PESA). On the antenna unit, which rotates at a speed of up to 30 rpm, a few digital interface signals as well as the electrical power supply necessary for feeding active electronics and elevation drives are needed. Four Gigabit-Ethernet channels are realized in a contactless way, whereas the power supply is realized with a classical slip ring module.

V. ENVIRONMENTAL REQUIREMENTS

The expectation of customers is increasing especially also for the environmental requirements. In the past ambient temperatures from -20°C to +55°C were specified, the today request goes down to -45°C and up to +85°. This is based on the trend that once a system is designed, it must be operable in all areas of the world.

Additionally the request (for stationary systems) to be used at high altitudes (up to 4500 m) is increasing the necessary electrical distances inside a slip ring. This can be realized with an increased slip ring length or additional shims in-between all the single slip ring ways. Both solutions do have a direct impact on the slip ring manufacturing cost.

To cope with humidity levels of up to 95% and the use of corrosion resistant materials is common design practice.

Modern systems are normally capable for dedicated requirements for vibration or shock, but for special cases sometimes tests are necessary. Often these tests can be used to demonstrate other requirements by transferring them by calculation with a FEM tool.

VI. LEGAL REQUIREMENTS

Legal requirements do influence radar systems more and more. Even as radar systems are often military equipment, an increasing number of system manufacturers specify the use of the safety and environmental standards which are necessary for civil applications.

Especially the European Government has established several regulations which need to be respected:

- Machinery directive 2006/42/EC
- Low voltage directive 2006/95/EG
- WEEE (waste electrical and electronic equipment) directive 2012/19/EU
- ROHS (restriction of the use of certain hazardous substances in electrical and electronic equipment) directive 2011/65/EU
- REACH Regulation (EC) No 1907/2006

These European directives have been transposed in several national laws and in adapted standards which ensure the compliance with the directives. In Europe the common standard for electrical safety is requested by the law ([5], [6]) which needs to be respected by the European supplier. Even if such safety standards do not need to be considered in other countries, due to the modular system and the standardization of the parts it is not possible to develop still rotary joints which do not fulfill the electrical safety requirements.

The European directives WEEE and ROHS as well as the REACH regulation are aiming to prevent environment and people from toxic substances. These requirements do reduce the design possibilities additionally, as e.g. lead is not allowed in solders and in aluminum or some surface coatings are prohibited (as chrome-VI containing coatings).

The problem between the (European) manufacturers and the operators or system integrator is often the different laws they have to comply with. Therefor a close cooperation and understanding is necessary. As not only European laws are increasingly demanding, all future concepts need designs which are respecting all these legal requirements.

VII. CONCLUSION

Designs for various transmission channels have been proposed. For future systems the following design principles are necessary:

- Replacement of contacting data slip rings by contactless Ethernet or optical joints.
- Modular systems including standardized interfaces and connectors for reduced development time and cost [4].

The key for the success of such a modern design is a close cooperation between the manufacturers of the radar system and of the rotary joint in order to achieve the best design solution respecting also the real demands in terms of environmental conditions.

REFERENCES

[1] F.L. Niemann, F.E. Ehlers, and F.T. Worrell, “Motional Joints” in G.L. Ragan (Editor), Microwave Transmission Circuits, chapter 7, New York: McGraw-Hill, 1948, pp. 451-455.

[2] H.-U. Nickel, H. Kugler, and K. Numssen, “Advanced rotary joints for radar applications – Modern design and manufacturing concepts”, Proc. of 2005 International Radar Symposium India, Bangalore, India, December 2005, LI-LVI (Invited talk ref. no. VI).

[3] H.-U. Nickel, and G. Friedsam, “Advanced rotary joints for radar applications – Fiber optical transmission channels”, Proc. of 2005 International Radar Symposium India, Bangalore, India, December 2005, Handout (Invited talk ref. no. VI).

[4] H.-U. Nickel, A. Doleschel, and M. Schmid: „Multichannel rotary joints for surveillance radars – State-of-the-art and future trends”, Proc. of 2013 International Radar Symposium, Dresden, Germany, June 2013.

[5] DIN EN 60664-1:2008-01; Insulation coordination for equipment within low-voltage systems - Part 1: Principles, requirements and tests.

[6] DIN EN 60950-1:2011; Information technology equipment - Safety - Part 1: General requirements.

BIO DATA OF AUTHORS

Andreas Doleschel was born 1972 in Munich, Germany. He studied mechnical engineer at the Technical University of Munich, where he finished his studies in 2003 with his thesis „Influence of lubricants on the efficiency of gearboxes”. Between 1997 and 2003 he was assistant at the gear research center (FZG) at TU Munich. In 2003 he joined EUROCOPTER where he worked first as a mechanical engineer, later as manager for mechanical drive system of helicopter applications. In 2012 he joined SPINNER as head of design for rotary joints.

Hans-Ulrich Nickel was born in Berlin, Germany, in 1962. He received the Dipl.-Ing. and Dr.-Ing. degrees in electrical engineering from the University of Karlsruhe, Karlsruhe, Germany, in 1988 and 1994, respectively. From 1989 to 1994, he was a Research Assistant with the Institute of Technical Physics, Nuclear Research Center KfK, Karlsruhe, Germany, where he was involved in the development of high-power gyrotron oscillators at 140 GHz and transmission components for millimetre waves.
In 1994 he joined Spinner GmbH, Munich, Germany, where he is engaged in the development of a wide variety of mainly passive radiofrequency components and sub-systems. Presently he is head of a radio frequency research and development department at Spinner GmbH.

Thomas Gebauer was educated at the University of Applied Science in Munich, Germany as mechanical engineer for aircraft design where he recieved his degree in 1997. Between 1997 and 2008 he work for EADS Germany in the department for retrofit and structural mechanical design. Since 2008 he is employed at SPINNER in the mechanical design department for high power components and rotary joints.