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## ROTARY JOINTS – INSTALLATION GUIDELINES

### 1 Purpose and Background

There are alternative ways of integrating a rotary joint within a turntable. While some ways do not cause problems, others will result in a substantial reduction of the rotary joints' service life. The latter can occur if the combination of turntable and rotary joint is statically indeterminate, which may result in constraining forces that can lead to a situation where the bearing of the turntable struggles against that of the rotary joint. As this loading happens periodically at every revolution, the constraining forces will most probably overload the bearing of the weaker partner, usually the rotary joint.

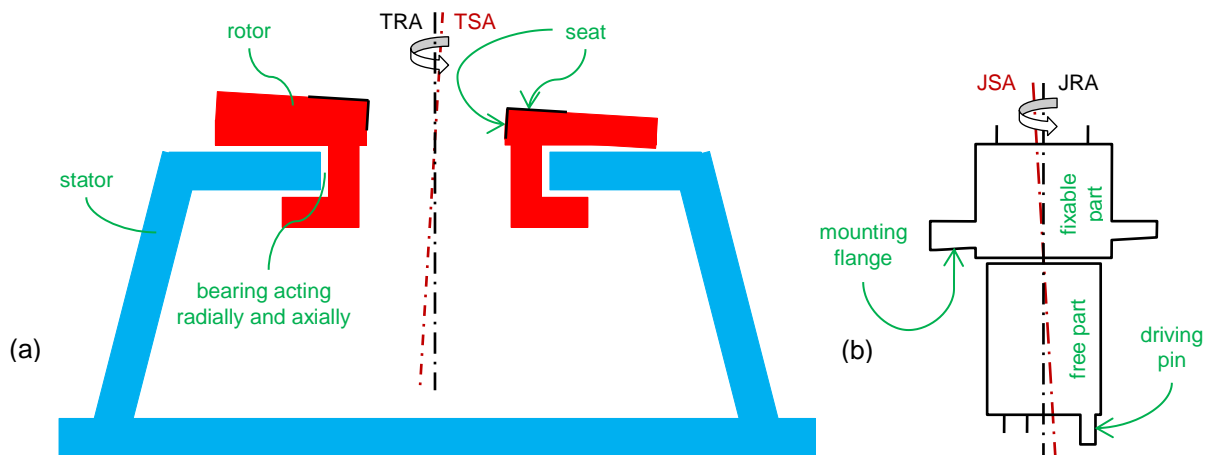
The aim of this document is to provide design advice and examples of how to avoid such a statically indeterminate situation and create a well-adapted design.

### 2 Definition of Terms

To make the situation easy to understand, we limit ourselves to a single-axis turntable geometry that corresponds to the azimuth axis of an antenna pedestal in a surveillance radar or a satellite ground station. The considerations discussed here based on a single azimuth axis can be applied to single axes of arbitrary orientation and eventually to multi-axis systems.

First, it is advantageous to define a set of terms related to both, the turntable and the rotary joint:

The turntable is composed of a stationary part, the **stator**, and a rotatable part, the **rotor**. Stator and rotor are shown in Figure 1(a) in blue and red, respectively. A radially and axially acting bearing (usually a rolling bearing) connects both parts and defines a rotational axis, namely the **turntable rotational axis TRA**. The turntable's rotor carries an area where the rotary joint is to be fixed, the so-called **seat**. This seat is characterized by a plane and a symmetry axis, the **turntable's rotor symmetry axis TSA**. As the plane is perpendicular to *TSA*, together they define a cylinder coordinate system, the so-called **turntable's rotor symmetry cylinder**.



**Figure 1.** Schematic longitudinal sections of a turntable (a) and a rotary joint (b). The colors indicate the rotational level, with blue illustrating the stator and red the rotor. The seat of the turntable and the mounting flange of the rotary joint are shown excessively inclined to highlight possible deviations between the axes of rotation and symmetry.

Like the turntable, the rotary joint also consists of two parts which can be rotated relatively to each other (Figure 1(b)). To avoid confusion with the turntable, we avoid using the terms stator and rotor here and call them the **fixable part** and the **free part**. The fixable part is usually identified by a mounting flange which is characterized by a plane and a symmetry axis, the **joint's flange symmetry axis JSA**. As the plane is perpendicular to *JSA*, together they define a cylinder coordinate system, the so-called **joint's flange symmetry**

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**cylinder.** The free part is where the driving of the rotary joint takes place, e.g. by means of a driving pin. A bearing within the rotary joint connects the fixable part with the free part and defines the **joint rotational axis JRA**.

### 3 Combination of turntable and rotary joint

#### 3.1 General considerations

The necessary and sufficient condition for a perfect interplay of turntable and rotary joint is the coincidence of the two rotational axes *TRA* and *JRA* (1).

$$TRA \stackrel{!}{=} JRA \quad (1)$$

The two symmetry axes *TSA* and *JSA* do not play a direct role for the interplay of the partners.

Unfortunately, there is no easy way to match the two rotational axes directly, e.g. by an adjustment procedure that compensates the axes tilt and offset. This is due to the general immaterial nature of a rotational axis. We thus must try to achieve axes' coincidence by means of an indirect way via the two symmetry axes. The producer of the turntable and the producer of the rotary joint must both pave the way for such an **indirect axes-matching**. Both must guarantee a maximum deviation between their respective rotating axis and their symmetry axis, i.e. *TRA* and *TSA* (2) as well as *JRA* and *JSA* (3) need to match within a certain accuracy. These **running accuracies** specify the radial and axial runouts, measured at the turntable rotor's seat and at the joint's mounting flange when rotated around their respective rotational axes.

$$\text{turntable running:} \quad TRA \stackrel{!}{=} TSA \quad (2)$$

$$\text{rotary joint running:} \quad JRA \stackrel{!}{=} JSA \quad (3)$$

If the running accuracy of each of the two partners is good enough it is sufficient to rigidly join their two symmetry cylinders by a properly chosen geometrical fit (4), e.g. by bolting them together.

$$\text{geometrical fit:} \quad TSA \stackrel{!}{=} JSA \quad (4)$$

However due to the detour via the symmetry axes, the indirect method will generally result in an imperfect matching of the rotational axes (5):

$$TRA \neq JRA, \text{ with } TRA \approx JRA \quad (5)$$

We now assume that the turntable and the rotary joint are rigidly connected to each other on one side. If one would also interconnect the other two sides of the rotary units in a rigid manner, the imperfect matching would result in an indeterminate system. As a result, the residual axes deviation would lead to constraining forces which must be avoided, as they will expose unnecessary dynamic loads to the bearings. Since a rotary joint's bearing is generally smaller – and thus weaker – compared to that of the turntable, it will sooner or later get destroyed by the dynamic load.

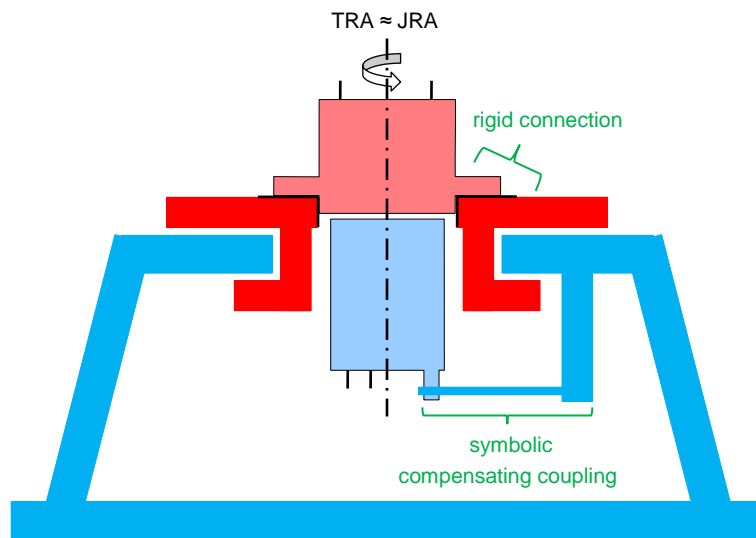
To avoid the described indeterminate system with its constraining forces we must only allow a single side of the rotary units to be connected rigidly. For the other side, a suitable compensating coupling must be provided which allows the required lateral play.

The two subsequent sections (3.2 and 3.3) demonstrate the four principle configurations for combining the rotary joint of Figure 1(b) and the turntable of Figure 1(a). In all cases one side is connected rigidly and the other side employs a compensating coupling. Practical types of compensating couplings are presented and discussed in section 3.4.

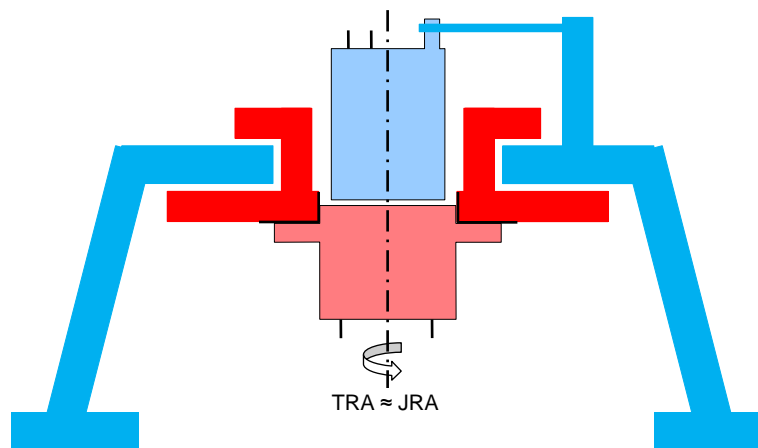
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### 3.2 Rigid connection between a joint's fixable part and a turntable's rotor

If we carry out the rigid connection between the rotary joint's fixable part and the turntable's rotor we need to install a compensating coupling between the joint's free part and the turntable's stator. Depending on the planned application one can choose between two basic configurations for the rigid connection – from above (Figure 2) and from below (Figure 3). A configuration according Figure 2 is often used for the azimuthal axis of an antenna pedestal of a surveillance radar (cf. [1], example 1) or a satellite ground station. The configuration shown in Figure 3 can be employed in industrial sensor systems like imaging microwave material scanners [2].



**Figure 2.** Rotary joint's fixable part connected rigidly from above to a turntable's rotor.

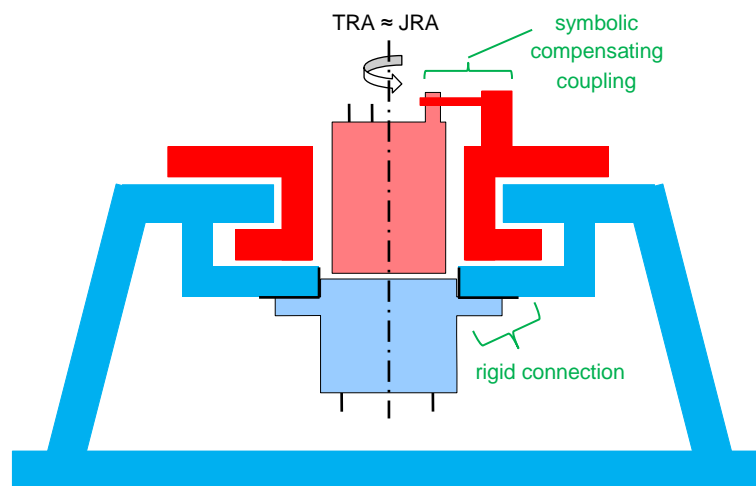


**Figure 3.** Rotary joint's fixable part connected rigidly from below to a turntable's rotor.

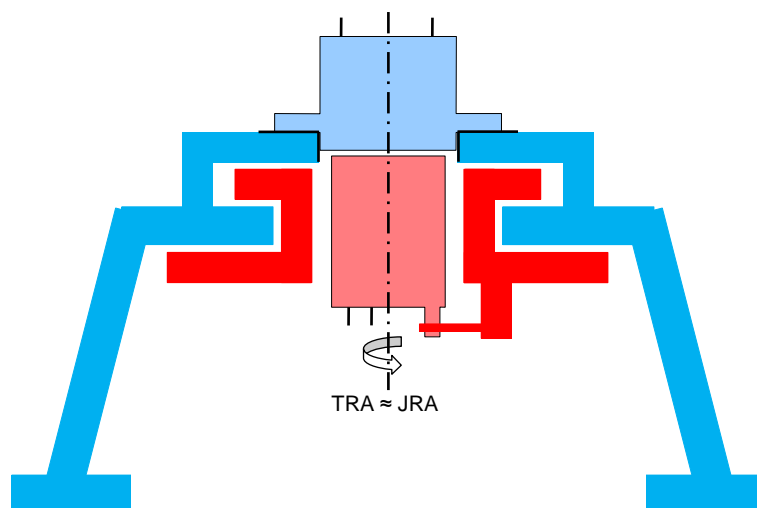
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### 3.3 Rigid connection between a joint's fixable part and a turntable's stator

If we choose the rigid connection between the rotary joint's fixable part and the turntable's stator we need to install a compensating coupling between the joint's free part and the turntable's rotor. Depending on the planned application one can choose between two basic configurations for the rigid connection – from below (Figure 4) and from above (Figure 5). A configuration according Figure 4 is also often used for the azimuthal axis of an antenna pedestal of a surveillance radar (cf. [1], example 2, 3, and 4). The configuration shown in Figure 5 is used in industrial sensor systems like imaging microwave material scanners (cf. [2], Figure 5(b)).



**Figure 4.** Rotary joint's fixable part connected rigidly from below to a turntable's stator.



**Figure 5.** Rotary joint's fixable part connected rigidly from above to a turntable's stator.

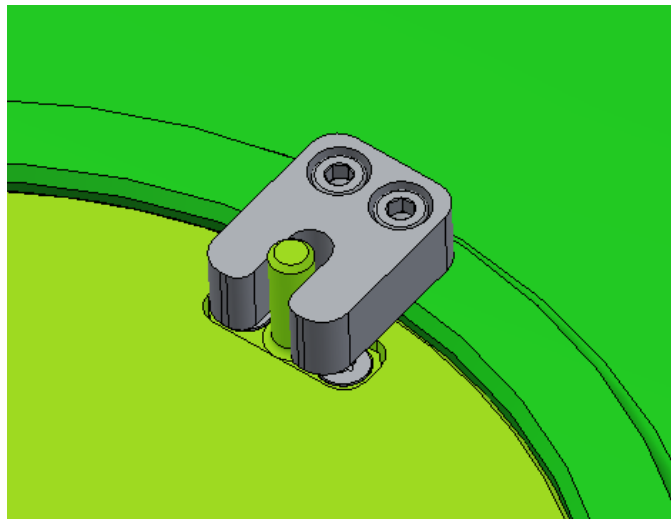
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### 3.4 Compensating couplings

In this section we discuss practical implementations of compensating couplings which are used in conjunction with rotary joints. These are the **pin-and-fork coupling** as per Figure 6, the **claw coupling** as per Figure 7, the **elastic coupling** as per Figure 8, the **link arm coupling** as per Figure 9, and the **bellows coupling** as per Figure 10. All these coupling types have in common that they provide the necessary play or softness in radial and azimuthal direction to avoid an over-determination.

The fact that the two coupled parts in Figures 6 to 10 have the same basic color (green) which differs only in brightness is to indicate that the parts are basically on the same rotational level, i.e. the stator or the rotor level, and that they experience only a tumbling movement relative to each other.

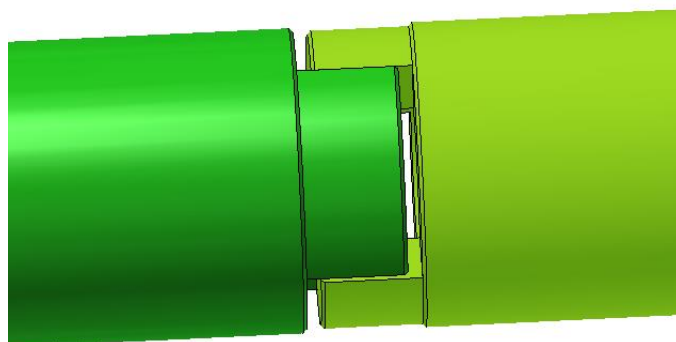
The compensating coupling shown in Figure 6 is composed of a driving pin and a fork. The fork must provide sufficient radial and angular clearance so that the pin does not drive against the fork during rotation. The design must also provide the necessary clearance in axial direction. Due to the necessary clearance the pin-and-fork coupling suffers from hard angular backlash, a feature that is not acceptable for many applications.



**Figure 6.** Pin-and-fork coupling [D05325].

In its simplest form the claw coupling, illustrated in Figure 7, consists of a claw comprising two parallel planes of its partner. For the necessary clearance the same principal conditions hold as for the pin-and-fork coupling. Thus, the conventional claw coupling also suffers from hard angular backlash.

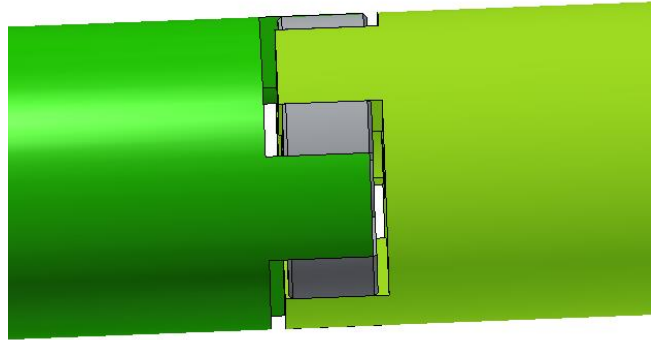
There is a variant of the claw coupling – the driver plate coupling – which uses an intermediate plate driven on and off by two orthogonally arranged claws. Since this coupling type requires almost no angular clearance, it can operate virtually backlash-free.



**Figure 7.** Claw coupling [D05327].

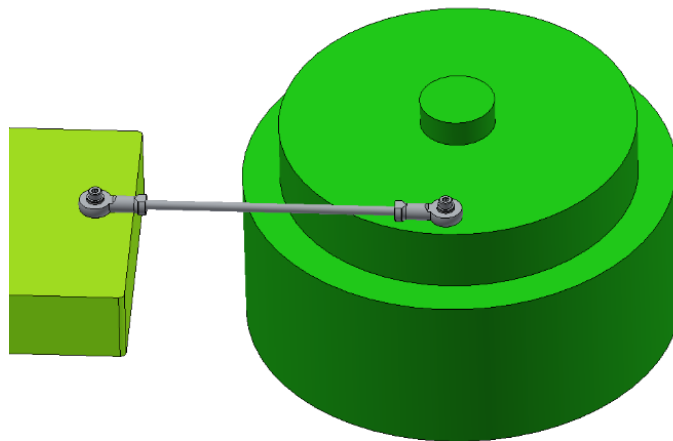
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The elastic coupling depicted in Figure 8 is very similar to the claw coupling. The main difference is, that the air-filled gaps of the claw coupling are now filled by elastic elements, e.g. rubber blocks. As a result, this coupling type has a soft, torque dependent angular backlash.



**Figure 8.** Elastic coupling [D05330].

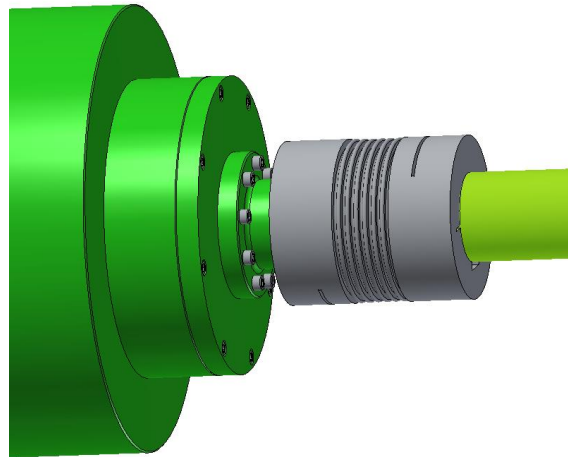
The link arm coupling shown in Figure 9 uses a link arm to connect two driving pins. As no play is necessary this coupling type operates practically backlash-free. The link arm coupling is often used in professional systems with large rotary joints where the driving pin can be fixed at a large radius.



**Figure 9.** Link arm coupling [D05339].

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The coupling shown in Figure 10 connects the two partners via metal bellows. Like the link arm this coupling type operates practically free of backlash. Since large metal bellows are rather expensive, the bellows coupling is mostly used in professional systems of small radial extent.



**Figure 10.** Bellows coupling [D05344].

The main advantages and disadvantages of the different coupling types are collected in Table 1.

**Table 1.** Comparison of compensating couplings for rotary joints.

designation	Fig.	advantage	disadvantage
pin-and-fork coupling	6	- easy to realize	- hard angular backlash due to play - periodically modulated rotational speed - subject to wear
claw coupling	7	- easy to realize	- hard angular backlash due to play - periodically modulated rotational speed - subject to wear
elastic coupling	8	- easy to realize - almost wear-free	- soft angular backlash due to torque dependent, elastic play - periodically modulated rotational speed
link arm coupling	9	- backlash-free - almost wear-free - inexpensive	- periodically modulated rotational speed
bellows coupling	10	- backlash-free	- periodically modulated rotational speed

It should be emphasized once again that the side equipped with a compensating coupling always suffers from a more or less pronounced tumbling movement. As a result, any constant rotational movement is overlaid by a sinusoidal angular oscillation. The amplitude of this oscillation is proportional to the extent of the misalignment of the two rotational axes *TRA* and *JRA*.

**Every rigid transmission line – whether coaxial line, waveguide or media pipe – that is to be connected to the tumbling side therefore requires a permanently flexible intermediate section.**

In rare cases, where only a very limited drive torque is required, a rigid transmission line can be used directly as the compensating coupling. For this purpose, the transmission line must be designed in such a way that it only has to perform very small elastic deformations. Such low-cost solutions are sometimes used in antenna test chambers in combination with small single-channel waveguide rotary joints.

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#### 4 Practical design examples

This section is planned for a later issue.

#### 5 References

- [1] Nickel, H.-U., Zovo, J., and Schmid, M., 2016, Refining radar architectures: Multichannel rotary joints for surveillance radars, IEEE Microwave Magazine, Vol. 17, No. 5, 60-74.
- [2] Nüßler, D., Schubert, M., Kose, S., and Pohl, N., 2017, Swifter security scanning: Millimeter-wave imaging with spin, IEEE Microwave Magazine, Vol. 18, No. 6, 70-78.