

Sphere-To-Cone Mating – New Solution to Improve Brake Tube Connector Sealing Robustness

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ABSTRACT

Recently invented solutions (Canadian Patent 2593305 and United States Patent Applications 20090015008 and 20070194567) incorporate sphere-to-cone type of the interaction between sealing surfaces in a brake tube connector. An interaction of sphere-to-cone type has numerous advantages over one with a cone-to-cone type which is currently utilized in conventional automotive brake tube connectors. Incorporation of a sphere-to-cone interaction between the sealing surfaces dramatically improves connector's sealing robustness. Sphere-to-cone based connectors are resilient to the tube and seat axes misalignment. Correspondingly, sphere-to-cone based connectors have less variation of the securing torque and virtually no propensity to locked misalignment occurrence. The article analyzes another fundamental advantage of a sphere-to-cone mating over the conventional cone-to-cone one. The analysis reveals that sphere-to-cone type of interaction demonstrates approximately one order of magnitude (10 times) less sensitivity to common dimensional variation. A Robust Design approach has been utilized for

sealing capability analysis and comparison. The transfer functions with respect to the sealing capability of both current cone-to-cone based connectors and new sphere-to-cone based connectors have been obtained and compared. The comparison suggests that for the same degree of sealing capability the dimensional and quality controls would be significantly simplified in case of sphere-to-cone based connectors manufacturing.

INTRODUCTION

A contemporary standardized brake tube connector has a cone-to-cone interface between its sealing surfaces. There are two mass-produced types: the "trumpet" type as per JASO F402 [1] or SAE J533 [2] standards and the "bubble" type as per SAE J1290 standard [3]. Both types demonstrate a deficiency of sealing robustness: some reworking is typically required in the course of the assembly process in order to properly seal many of them [4, 5].

A connector arranges the proper mutual positioning and clamping between tube flare and port. The flare's sealing surface is an integrated part of its abutment surface. When a connector is being secured, the flare's sealing surface mates with its counterpart onto the port's seat aiming at developing a seal. A good and robust connector's sealing may be expected only if an adequate clamping force is supplied at the ring-like shaped contact area of sufficient size between the sealing surfaces.

There is a fundamental shortcoming of the cone-to-cone mating. A ring of contact may be expected only if the axes of both the flare and the port coincide. Otherwise, it is common that the cone-to-cone interaction results in a crossing (i.e., having a geometry entity which belongs to both cones) in just a single point. Strictly speaking, a single point initial contact occurs at one of the frustums edges (a frustum is a cone with a cut off vertex). If the frustums touch by their side surfaces the initial crossing is a straight line there.

Since a ring-shaped initial contact is not guaranteed, a connector must be designed with certain capacity to reinstate a desired ring-shaped mating area. Correspondingly, certain amount of both self-adjustment and reasonable sustained deformation (while the connector is being secured by torque) is expected. This is the design intent to overlap common disturbances and deviations in that way. Accordingly, certain amount of the securing torque is consumed to support such

robustness, which, in turn, causes the variation of the torque required to seal the connector.

Contemporary standardized brake tube connectors with cone-to-cone mating maintain a limited sealing robustness as certain conditions may lock the flare in a misaligned state against the seat due to friction [4]. Simply put, if the initial contact occurs on a single point, the flare may become locally squeezed at this spot. If the effective friction coefficient at that squeezed area becomes greater than a certain threshold then the flare gets locked (pinned) against the seat. This inhibits self-adjustment as mutual motion of the components becomes restricted. Accordingly, the expected amount of extra torque may not be able to transform the poor initial contact into an uninterrupted circular line anymore. At the same time, a reasonable torque increase may become insufficient to provide the deformation needed to close the gap between the sealing surfaces. In this case further torque increase leads to a squashing of joint's components, which in turn can permanently preclude development of the seal.

At least two factors greatly affect the probability of a locked misalignment occurrence. Local surface defects and deviations at that squeezed area (like sharp edges, groves, notches, etc. and even common surface roughness irregularities) may dramatically increase the effective coefficient of friction there. The second factor is the level of external disturbances causing a misalignment between the flare's and the seat's axes.

Combination of those two factors greatly increases the chance that initial single-point contact remains insufficiently transformed. Correspondingly, the probability of a leak instead of a sealed connector increases as well. However, even if a locked misalignment did not occur, the torque variation may become unacceptably high.

For example, picture a side force which is applied onto the tube along the direction of increasing the initial minor misalignment of the axes (a typical situation during brake tubing assembly process). This unfavorably changes the force balance in the connector during its securing. Simply put, the amount of torque which was sufficient in case of “usual” disturbance level may become inadequate to achieve the seal with the presence of an excessive side force (which consumes certain amount of available self-adjusting capacity). Accordingly, some extra torque will be necessary for the connector’s self-adjustment to overlap the side force impact and transform the initial poor contact into a ring. If extra torque is not available at the assembly station then a leak and corresponding rework is unavoidable (this is also typical for a conventional plant assembly process having a “preset” torque).

Recently invented automotive brake tube connectors with sphere-to-cone type of sealing surface mating are resilient to angular axes misalignment [6, 7 and 8] . Contrary to cone-to-cone mating a sphere-to-cone mating does not require a perfect axes alignment. It is common that the result of sphere-to-cone surfaces crossing

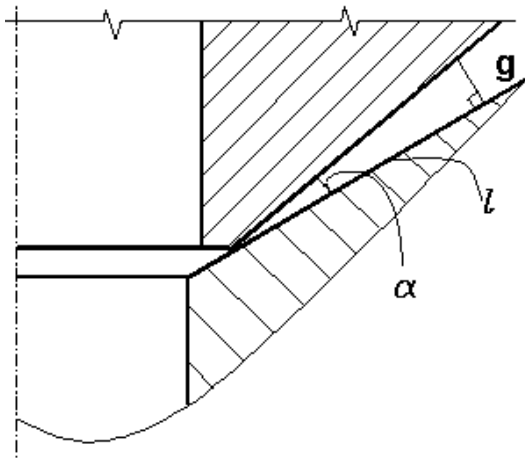
(i.e., having a geometry entity which belongs to both surfaces) is a circumference. Therefore, a ring-shaped initial contact is expected even if the tube and seat axes are not parallel. Accordingly less torque variation is expected as no torque is anymore consumed to transform a single-point initial contact into a desired ring.

Insensitivity to angular axes misalignment and less torque variation are not the only advantages of the new connectors. There is another fundamental advantage which is present even if there was no misalignment. A sphere-to-cone interaction enables greater stability to the size of the ring-shaped contact with respect to dimensional variation of the sealing surfaces. To explain this advantage let us analyze theoretical sealing capability from a geometrical standpoint and compare new and existing solutions.

SEALING CAPABILITY MODEL IN CASE OF A CONE-TO-CONE MATING

Currently utilized standardized connectors with cone-to-cone mating will be the baseline to our comparison. The interaction between two coaxial cone frustums is shown on Figure 1 (half of the connector’s cross-section along the common axis; the holes at the axis represent the connector’s passage). In this case, the gap between the frustums (immediately after their initial mutual contact as per the design intent) takes the shape of a wedge.

Figure 1



The gap (denoted as **g**) can be represented by the smallest side of the right angle triangle on the cross-section. The size of this gap depends on the mutual angle between the frustums (denoted as α) and the length of the other side of the triangle (denoted as **l**). Since α is a small angle (as the mating cone frustums must be similar per the design intent) the following is true as long as α is measured in radians: $\alpha = \sin \alpha = \tan \alpha$. Therefore the dependency can be described by the following simple formula:

$$l = \frac{g}{\alpha} \quad (1)$$

The length **l** can be utilized as a geometrical or theoretical sealing capability criterion. Zero **g** (or no gap condition anywhere between the sealing surfaces) is not a sufficient criterion to achieve a sealed connector's state. Even when nominal **g** is zero at the point of initial contact (the point on the cross-section picture above represents the

circumference) there will always be an actual gap of more than zero somewhere around the circumference due to unavoidable deviations, defects, surface roughness and other common irregularities and imperfections. Those "few microns" wide gaps are expected to become "closed" by self-adjustments and sustained deformation of connector's parts during the connector securing assembly operation (torquing). That is why in practice, a nominal gap which is a little bigger than zero does not mean that a sealed state is unachievable. Accordingly it is important to design a connector in such a way that there is a sufficient mating area where the geometrical gap is "closeable" – i.e. less than a certain threshold.

It is the industry wide practice to accept nominal gap of 10 to 25 microns as such threshold. The length **l** shown on the cross-section above represents the area where the gap is less than such, given a threshold **g** (i.e. sealable). In the framework of this geometrical model we will call **l** "the length of contact". The greater the mating area (with the gap which is less than the threshold **g**) the more probability there is to seal the connector by securing it with a given torque. Accordingly, the length of contact is a criterion for sealing capability – the longer is the **l** the higher is the probability to achieve a sealed state in a given connector.

Let us calculate the length of contact in the current standardized cone-to-cone connectors.