

Expanding Bell Seal Improves Reliability, Reduces Inlet Steam Leakage and Simplifies Assembly

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Abstract

As the power generation industry moves into the “deregulation age”, steam turbine owners and operators are under significant competitive pressures to improve the efficiency of their equipment and to make sure that costs associated with the operation and maintenance of their systems do not cause them to become uncompetitive. Additionally, clean air policies and other environmental pressures further challenge power producers’ competitive strategies with the additional costs of compliance. Per unit costs for critical resources, such as fuel and labor, are generally beyond the significant control of equipment O&M teams. However, efficiency and maintainability of turbine components and systems can contribute significantly to the reduction in total resource consumption, and hence, significantly reduce owners’ overall cost to produce; thus providing them with the competitive edge needed to succeed in their changing market.

This presentation will focus on the drawbacks that exist in the current design of one critical steam turbine component: steam inlet bell seals. The authors will discuss the shortcomings of the current design with respect to material selection and geometry -- shortcomings which contribute to increased resource consumption and downtime, thus negatively impacting power producers’ competitiveness. Further, this presentation will introduce an available effective solution to these shortcomings; a solution that will provide owners and operators with additional means for reducing their power production costs.

Current steam inlet bell seal assembly designs, in use for many years, utilize Stellite and Chromium Molybdenum (Chrome-Moly) materials. Shortcomings of the current design can contribute to significant maintenance problems as well as degradation in turbine efficiency during operation. The bell seal assembly components, some of which are susceptible to high oxidization, are prone to interference problems and can freeze up during operation. The combination of these shortcomings frequently results in damage to components, costly repairs, efficiency loss and consequent increased stack emissions for a given power output. Similar problems have existed for many years with other types of inlet seal designs.

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One power plant user of a similar such turbine OEM design states that, “Prior to putting in [the new seal design], we had experienced several costly problems with the conventional inlet snout seal rings. In previous inspections, excessive time was spent in trying to remove the upper outer casing, the lower inner casing, and the expansion joint assembly for blowdown valve connection. Once you finally get the machine apart, you are probably faced with additional workscope leading to an increase in your outage budget or the elimination of other work.”¹

It is believed that an improved bell seal assembly design, one which addresses the inherent shortcomings of the current design, will significantly help power producers to reduce many of the troublesome, time consuming, and costly obstacles associated with the current bell seal design; while improving efficiency and consequently reducing overall fuel costs and stack emissions.

Introduction

In steam turbines, it is necessary to deliver steam from the main inlet pipe through the outer and inner cylinders (Fig. 1) into and through the nozzle chambers. For certain turbine OEM designs, steam flows from the main steam inlet pipe and into the nozzle chambers through the turbine cylinders via the inlet sleeves. To retain the steam within the cylinders and nozzles -- minimizing leakage between them -- inlet sleeves are “connected” to the nozzle chambers by a bell seal assembly (Fig. 2). This arrangement is intended to, among other things, provide some freedom of movement between major (cylinders and nozzles) components.

¹ B. Glynn, H. Reiss; Improved Inlet Seal Design, Power-Gen Americas '95, Anaheim, CA, December 6, 1995.

The bell seal was specifically designed to seal the area between the steam inlet sleeve and the nozzle area. This area of the turbine assembly surrounds a steam flow that is approximately 1000 degrees Fahrenheit and is pressurized to as much as 3600 pounds per square inch. To fully understand the implications of an improved seal design, it is important to understand that the turbine cylinders experience different rates and magnitudes of thermal expansion during turbine startup and operation because of the way steam flows over and through these components. The seal design must, therefore, be capable of accepting vertical, axial and transverse differential expansion relative to the major components. In opposition to this requirement for freedom of movement, tight clearances must be maintained so as to minimize steam leakage losses.

Conventional Bell Seal Design

Original technologies originally dictated the design of conventional bell seal assemblies to consist of the bell seal, a flanged retaining nut, and a locking screw. In these conventional designs, the bell seal is fabricated from a Stellite material. The other components: the nut, locking screw, inlet sleeve and nozzle chamber neck are typically made of Chrome-Moly Steel (Fig. 3).

To allow for assembly, as well as differential thermal expansion and contraction due to temperature gradients, the conventional bell seal is designed with between two and three mils (0.002" to 0.003") of radial clearance between the seal and the nozzle bore at ambient conditions. This typically permits a steam leakage of between one quarter and one percent (0.25 to 1.0 %) of main steam flow between the bell seal and the nozzle bore during operation, depending on bore diameters and steam pressure (Fig 4). This compromise, intended to allow for differential expansion and to facilitate assembly and disassembly of the components, results in significant losses in efficiency. These apparently mutually exclusive design objectives provided the impetus for TurboCare's design initiative.

Greater radial clearances between components during assembly and startup would be a feature which would provide maintenance teams with the benefit of quicker and easier disassembly and reassembly, while also allowing for significant relative movement between inner/outer cylinders and the nozzle box during periods of thermal distortion. The added advantages to the maintenance team would be less frequent replacement of parts, reduced occurrence of

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nozzle bore and inlet sleeve damage; as well as reduced mechanical stresses in the top hat area. This would benefit the team by reducing costly downtime, replacement parts, and major welding and machining repairs.

Although greater clearances between components during assembly and startup would be preferred; a positive, yet “floating”, seal was desirable in order to improve leakage characteristics and increase efficiency. This improved efficiency feature would provide the turbine operators with the advantage of reduced fuel consumption with a consequent reduction in stack emissions. The benefits to the operating team would be reduced fuel dollar expenditures as well as a means to voluntarily comply with strengthening political environmental pressures.

In addition to the radial clearance between the seal and the nozzle bore, an axial clearance between the nut flange and the bell seal flange (Fig. 5) is desired to allow the bell seal to “float” between the nozzle chamber and the inlet sleeve during assembly and start up. During turbine start up, the seal and inlet pipes-- at ambient temperature -- are exposed to relatively high temperatures and pressures over a relatively short period. This temperature gradient results in significant thermal distortion of major components, including inner and outer cylinders, nozzle blocks, and inlet sleeves.

Typically, adverse environmental conditions existing within the turbine dictate that a variety of materials be used for different applications. For example, the components in the bell seal portion of the assembly must exhibit qualities of strength and toughness. The bell seal itself is typically manufactured from Stellite-6, which is a highly erosion resistant and tough material. Other components, such as the nut which is used to attach the bell seal to the inlet sleeve, are typically made from CrMo. This material is a relatively soft and malleable steel which is susceptible to oxide buildup.

These materials react very differently to the corrosive, erosive, and thermal environments that exist within the turbine. Typically, they do not optimally react in manners that enhance the performance and maintainability of turbomachinery equipment.

As noted above, steam inlet components are exposed to temperatures of approximately 1000 degrees F. At these temperatures, a thin layer of oxide buildup forms on Ferritic material surfaces. This oxide layer, frequently as much

as ten mils (.010 inches) thick, can interfere with the close radial and axial clearances existing in the conventional bell seal and nut assembly.

When the oxide layer forms on the retaining nut, it quickly fills up the clearances between the nut and bell seal flanges, contributing to lock up of the bell seal. In some cases, the bell seal becomes so locked up that it must be destroyed completely during disassembly, further compounding the maintenance problems that become increasingly difficult and expensive. As differential expansion increases, movement of the seal can become restricted, resulting in high stresses in the major components and in the entire bell seal assembly. Physical/mechanical distortion and damage to the entire assembly can result, leading to increased levels of steam leakage and lost efficiency.

After the nut threads and flange have become coated with oxide, the nut often becomes difficult to remove in the normal fashion, and must frequently be cut out -- a very difficult, time consuming, and costly process. In addition, bell seals that have been operating under harsh environmental conditions for several years become very difficult to separate without galling the nozzle box during disassembly. When galling does occur, it is generally necessary to re-machine the nozzle chamber -- also a very time consuming and costly operation.

Additionally, it is not uncommon for further damage to occur due to the effects of erosion. If the bell seal allows for extensive periods of leakage during operation, and if particulate material is contained in the steam coming from the boilers, erosion may occur on the steam inlet components. The erosion damage inevitably results in costly repairs to the nozzle chambers and bell seals.

Current Design Summary

Current bell seal designs experience shortcomings that can negatively impact the competitiveness of power producers.

- ⇒ Excessively tight ambient and startup clearances make disassembly and reassembly difficult, time-consuming, and costly.
- ⇒ Excessively tight clearances restrict differential expansion between major turbine components resulting in high stresses and frequent damage.
- ⇒ High oxidation rates of certain components of the bell seal assembly restrict movement and promote binding between components, thus exacerbating the problems of lockup and galling.

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- ⇒ **Tight clearances and oxidation contribute to increased friction forces during periods of thermal distortion, thus further limiting component mobility and contributing to bell seal and nozzle bore damage.**
- ⇒ **Operating clearances between the bell seal and nozzle chamber results in excessive steam leakage, preventing turbine operators from achieving and maintaining optimum efficiencies.**
- ⇒ **Shortcomings of the current bell seal design can contribute to longer outages, increased parts replacement costs, increased fuel expenditures, and increased stack emissions; all of which reduce the competitiveness of the power production facility.**

Development of a Solution

For TurboCare, the goal was to develop a solution that would provide power plant O&M departments with a means for reducing their operating and maintenance costs, thus assisting them to more effectively compete in the rapidly changing power market. The essential technical objectives of this solution were identified as:

- 1. Relatively high seal to nozzle bore radial clearances at assembly;**
- 2. Moderately high seal to nozzle bore radial clearances with freedom of “float” during periods of high thermal distortion;**
- 3. Zero steam leakage at normal operating conditions;**
- 4. Axial seal flange to retaining nut flange clearance at all conditions.**

In order to meet these critical technical objectives, it was vital that design engineers involved in the development project thoroughly understand the material characteristics and highly variant operating conditions of the turbine itself. Therefore, extensive finite element modeling of turbine casing, inlet sleeve, nozzle box, and bell seal assembly interactions were performed. These models provided significant insight into some of the dynamics and mechanical stresses which affected these areas.

An Already Existing Solution Technology

Initial review of the design requirements indicated that existing advanced technology, previously developed by TurboCare for other turbine OEM inlet seal applications, could be extrapolated to the bell seal problem discussed above. TurboCare's Articulated™ Snout Ring design, which has been in use since 1990, has proven to solve many of the problems identified above for turbines manufactured by another major OEM. To date, the Articulated Snout Ring design has been successfully applied to more than 200 inlet snout pipes, and users have reported very positive results.

One user reports, "In the fall of 1994, the turbine was disassembled for repair to the inner cylinder bolting and joint. At that time, we got to test out TurboCare's claims for their Articulated™ Snout Rings. Disassembly went very well with no hang up on the snout pipes, and when we inspected the nozzle block snout pipe, we had no damage...We at New England Power Co., Brayton Point Station, are very pleased with this new product. Now that the utility industry is changing, upgrades like this one help to control cost and keep efficiency high."²

Because reported results of this established and proven technology were so favorable, it was determined that it should be reviewed for application in the bell seal area.

Existing technology, as applied to the bell seal problem, would utilize two sets of superalloy (of industry-accepted material composition) rings that would fit loosely at assembly and disassembly, would exhibit desired "float" characteristics at all conditions, and would provide a positive zero-leakage seal at operating conditions. The non-Ferritic super alloy rings would have characteristics of high lubricity, and would not be susceptible to oxide buildup. This combination of material properties would provide for minimum friction and reduced stresses.

The mechanics of one version of the design would utilize an independent flanged ring carrier to support the seal rings, which would be attached to the inlet sleeve by a flanged retaining nut (Fig. 5). Another version would utilize a single-pieced integrated flanged ring carrier/retaining nut configuration (Fig. 6). Depending upon the specific application, either version could be selected,

² B. Glynn, H. Reiss; Improved Inlet Seal Design, Power-Gen Americas '95, Anaheim, CA, December 6, 1995.

although the two-piece version shown in figure 5 is generally preferred due to its additional two degrees of freedom between the carrier and inlet sleeve.

Both designs, shown in figure 5 and figure 6, would utilize two alternating sets of inner and outer seal rings. A set of inner rings would be engineered with an inner diameter clearance at assembly, but would differentially **contract** in relation to the carrier as operating temperature is increased, thus forming a **zero-leakage** seal with the outer diameter of the carrier. In opposition, a set of outer rings would be engineered with an outer diameter clearance at assembly, but would differentially **expand** into the nozzle bore as operating temperature increased, thus forming a zero-leakage seal with the inner diameter of the nozzle bore. These designs also incorporate the added feature of crowned sealing surfaces (Fig. 6). These crowned surfaces provide the advantage of predictable, controllable, and stable sealing contact; thus providing the additional benefit of better leakage control and reduced efficiency losses.

Both designs also provide for a positive ring stack clearance (in the direction of the pipe axis), which ensures that inner and outer seal rings are permitted to slide freely with relation to each other. This provides adequate freedom of movement, or float, as desired to minimize mechanical stresses. Sealing between the individual ring surfaces themselves is facilitated by steam differential pressure which tends to squeeze the rings together in the axial direction.

The rings of these designs should not to be confused with a “piston ring” design, as all rings in this improved design are stacked in contact with each other, which provides significant vibration damping. In addition, because seal rings are in positive contact with the ring carrier and/or the nozzle bore during normal operation, problems of galling and fretting previously associated with piston rings and flow induced vibration will not occur.

As part of TurboCare’s analysis of these dynamic ring seal designs, detailed Finite Element Models (FEM) were developed to investigate the reliability of the system. In addition to proving the mechanical integrity of the designs, results showed that the first outer seal ring (the one supported by the carrier flange) is not only affected by the compressive contact loading by the nozzle chamber, but also is significantly affected by the steam pressure load of up to 3600 PSI on its exposed surfaces. Understanding the loaded combination of these stresses is critical to the proper design and application of this technology.

All of these dynamic clearance control technologies can be properly integrated into an effective sealing system only by careful material selection and proprietary engineering of ring quantities and geometries.

A More Elegant, Simpler Solution

TurboCare has further expanded its selection of inlet seal solutions to include a “ringless” design (Fig. 7), which incorporates essentially all of the design features and benefits of the rings and carrier into a single-piece integrated assembly. This design, while appearing simpler and more elegant, also allows for relatively high assembly and startup clearance, allows for float, and provides a crowned zero-leakage seal during normal operation. In order to provide the freedom of movement required to minimize mechanical stresses, this design must utilize a separate engineered sealing body and retaining nut, but does not require the use of multiple alternating independent seal rings. Sealing between the seal body and nozzle bore is achieved by actively controlled contact of the crowned sealing surfaces.

At the inner diameter of the ringless seal are a series of slanted labyrinth teeth which provide the additional benefit of causing any flow which does pass, particularly during startup when the outer diameter is in its clearance configuration, to become turbulent. This turbulent disruption further reduces any leakage flow past the seal assembly. The geometry of these teeth are such that they are intended to be sacrificial in the event of substantial misalignment between the casing and inlet sleeve.

Summary

The existing steam inlet bell seal design suffers from shortcomings which can result in increased machine stresses, damage to major components, increased steam leakage and fuel consumption, increased stack emissions, and an overall increase in operating and maintenance costs. These increased O&M costs negatively impact power producers’ total cost of production and can be detrimental to their competitive position in the changing “deregulated” market. Some of these shortcomings, described above, include:

- ⇒ Excessively tight ambient and startup clearances;
- ⇒ High oxidation rates of certain components of the bell seal assembly;

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- ⇒ **Non-zero operating clearances between the bell seal and nozzle chamber;**
- ⇒ **Parallel sealing surfaces between the bell seal OD and the nozzle bore ID.**

These shortcomings of the current design can result in the following operational and maintenance problems:

- ◇ **Restriction of differential expansion between major turbine components;**
- ◇ **Unstable, potentially high stress sealing contact between bell seal and nozzle bore contributing to component damage;**
- ◇ **Difficult, time-consuming, and costly disassembly and reassembly procedures;**
- ◇ **Excessive steam leakage, resulting in increased fuel consumption and stack emissions;**
- ◇ **Extended turbine outage durations.**

TurboCare, a premiere supplier of turbomachinery maintenance parts and services, has developed a variety of solutions which will provide power plant O&M departments with a means for minimizing associated problems, thus reducing their operating and maintenance costs. This will assist them to more effectively compete in the rapidly changing power market. The primary features of these solutions are:

- 1. Re-engineered bell seal assembly geometry;**
- 2. Material improvements, utilizing industry-proven material selection;**
- 3. Implementation of proven active sealing technology.**

The advantages of these solutions include:

- 1. Relatively high seal to nozzle bore radial clearances at assembly;**
- 2. Moderately high seal to nozzle bore radial clearances with freedom of “float” during periods of high thermal distortion;**

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- 3. Zero steam leakage at normal operating conditions;**
- 4. Positive axial seal flange to retaining nut flange clearance at all conditions;**
- 5. Stable crowned sealing surfaces.**

The power plant owners, operators, and maintenance teams benefit from these solutions by:

- ⇒ Reducing mechanical stresses in major turbine components;**
- ⇒ Reducing the amount of unplanned repairs require during an overhaul;**
- ⇒ Reducing the frequency and cost of replacement parts;**
- ⇒ Reducing disassembly and reassembly time and costs;**
- ⇒ Improving and maintaining optimum turbine efficiency and reducing total fuel consumption costs;**
- ⇒ Reducing excessive stack emissions which result from inefficient operation.**

The bottom line benefit of these solutions is an overall reduction of power plant production and maintenance costs, providing the edge required to succeed in today's highly competitive power market.

List of Figures and References

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Fig. 3: Close up view of bell seal assembly.

Fig. 4: Diagram of conventional bell seal indicating steam leakage.

Fig. 5: Close up of improved bell seal area showing axial flange clearance and separate ring carrier with retaining nut.

Fig. 6: Diagram of improved bell seal with integrated ring carrier/retaining nut assembly and exaggerated crowning.

Fig. 7: Image of improved integrated carrier/seal design.

Fig. 8: Photo of improved integrated carrier/seal design.

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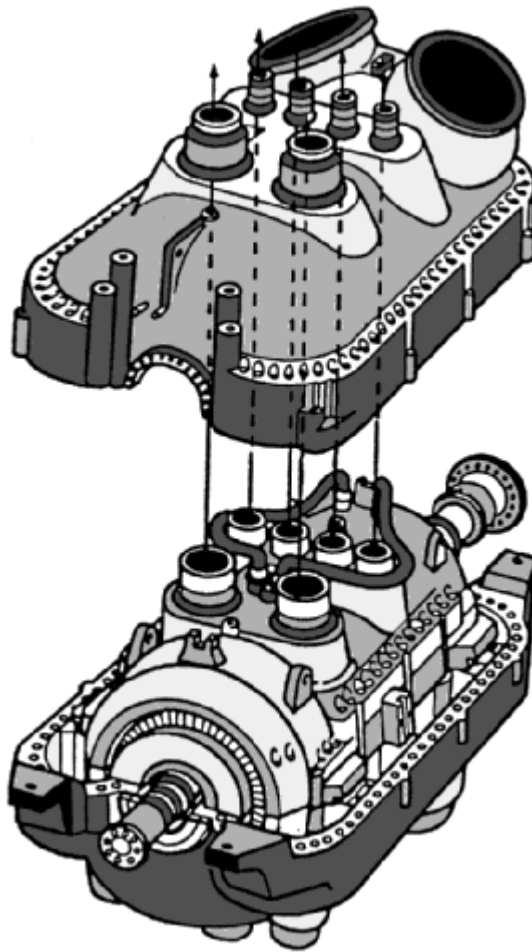


Figure 1 -- Outer & Inner Turbine Cylinder

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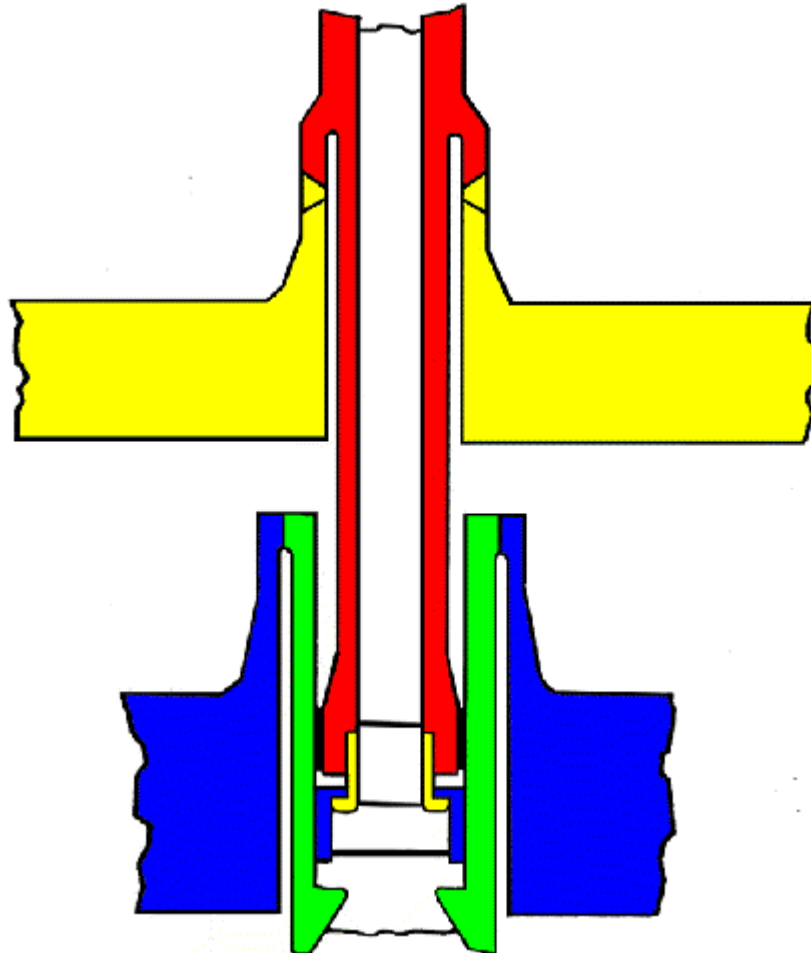


Figure 2 -- Intermediate View of Outer/Inner Cylinder Interface

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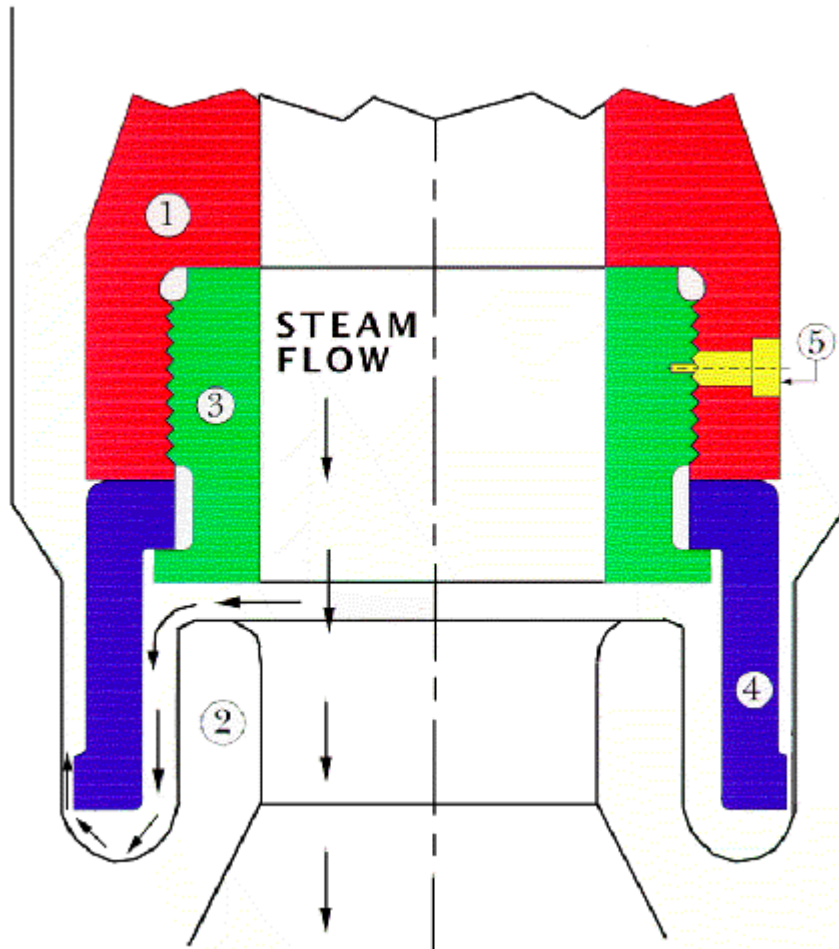


Figure 3 -- Close-up View of Conventional Inlet Bell Seal Assembly

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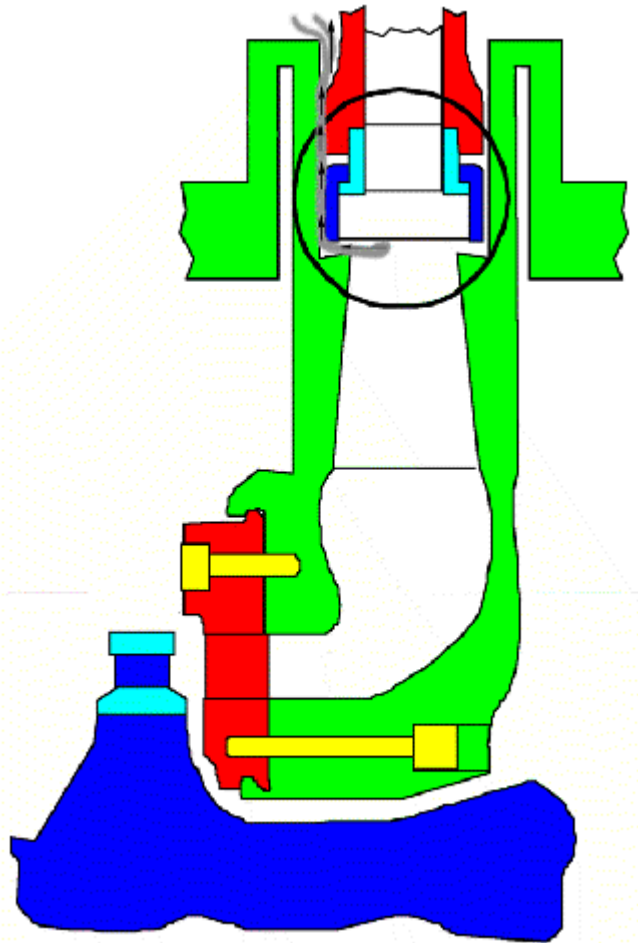


Figure 4 -- Intermediate View of Inlet Pipe, Nozzle Area, and Bell Seal Leakage

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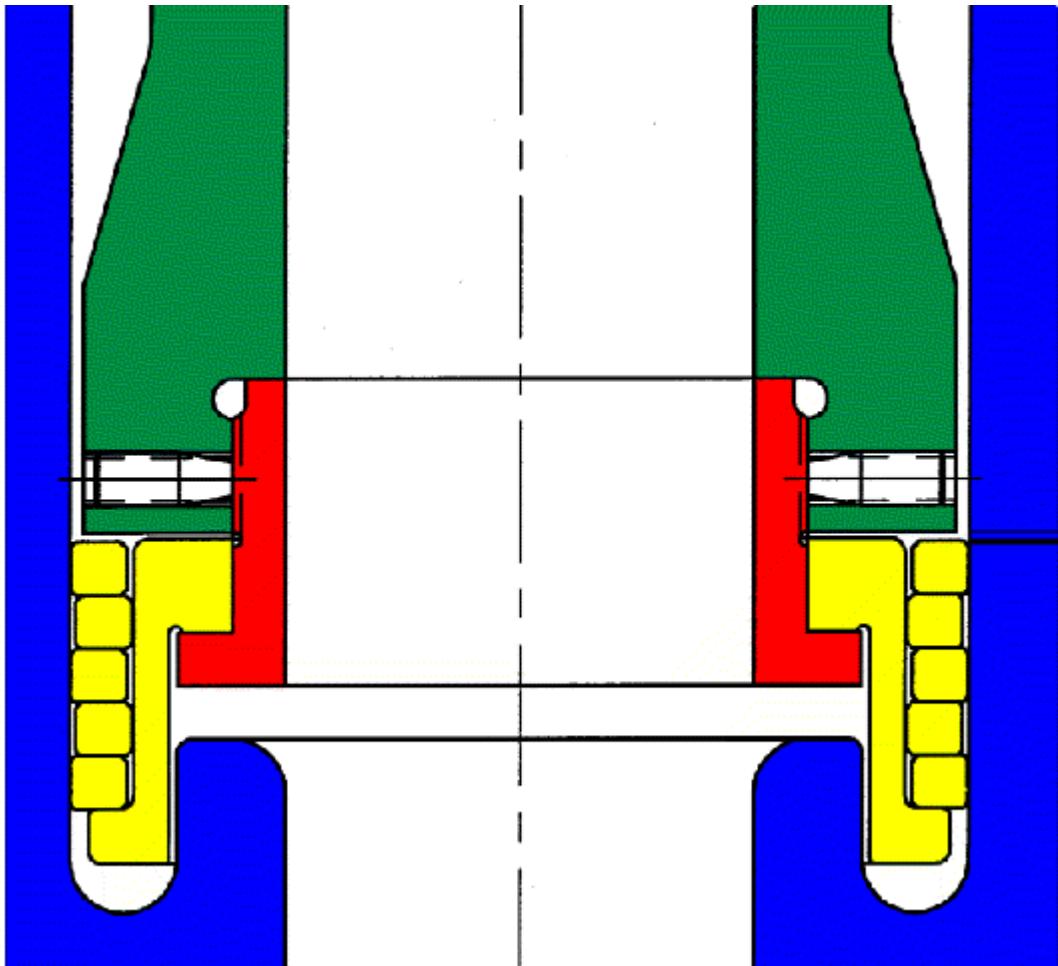


Figure 5 -- Improved Bell Seal Assembly with Separate Retaining Nut

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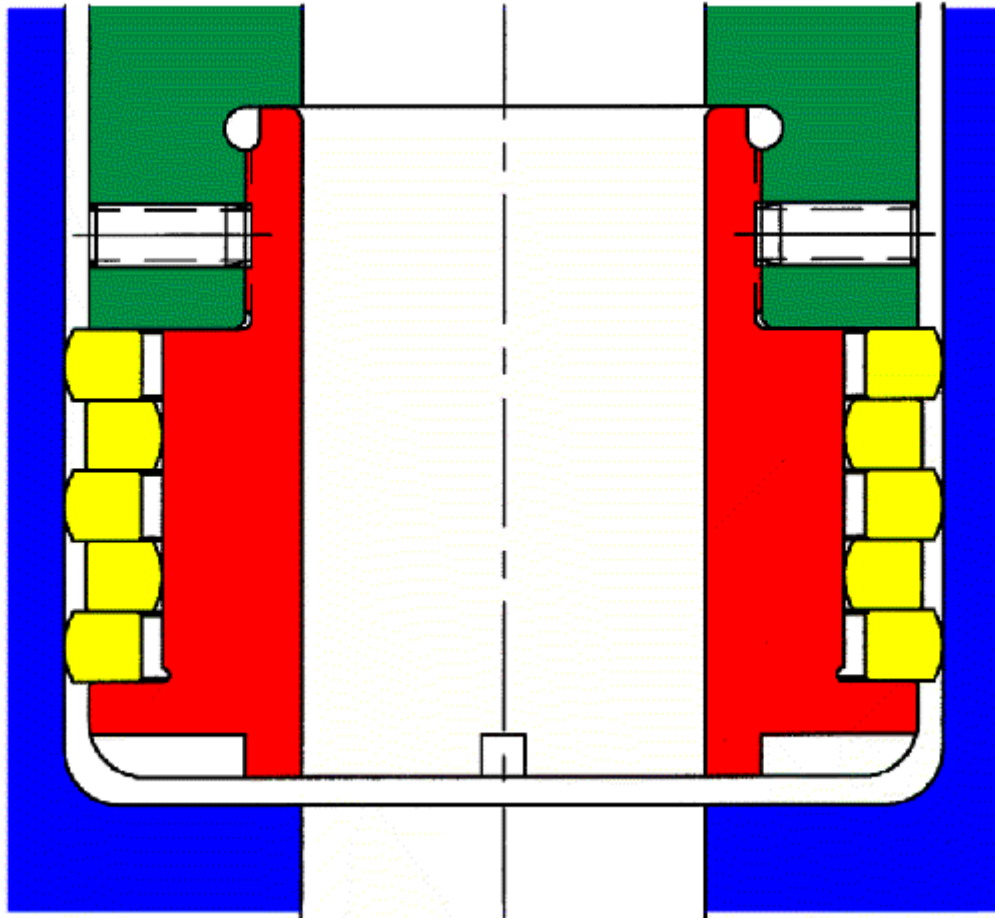


Figure 6 -- Improved Bell Seal with Integrated Retaining Nut

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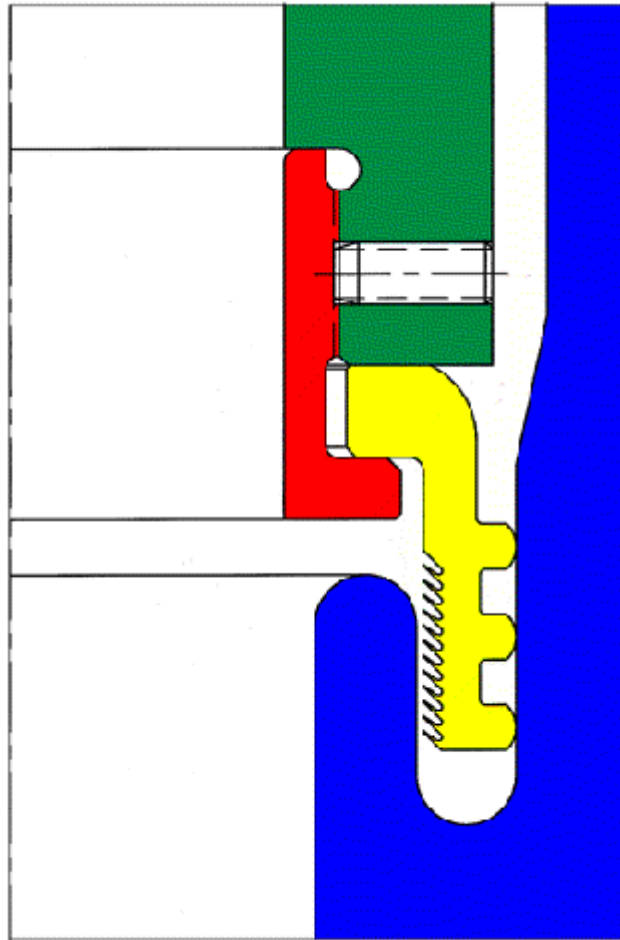


Figure 7 -- Fully Integrated Carrier/Seal Design

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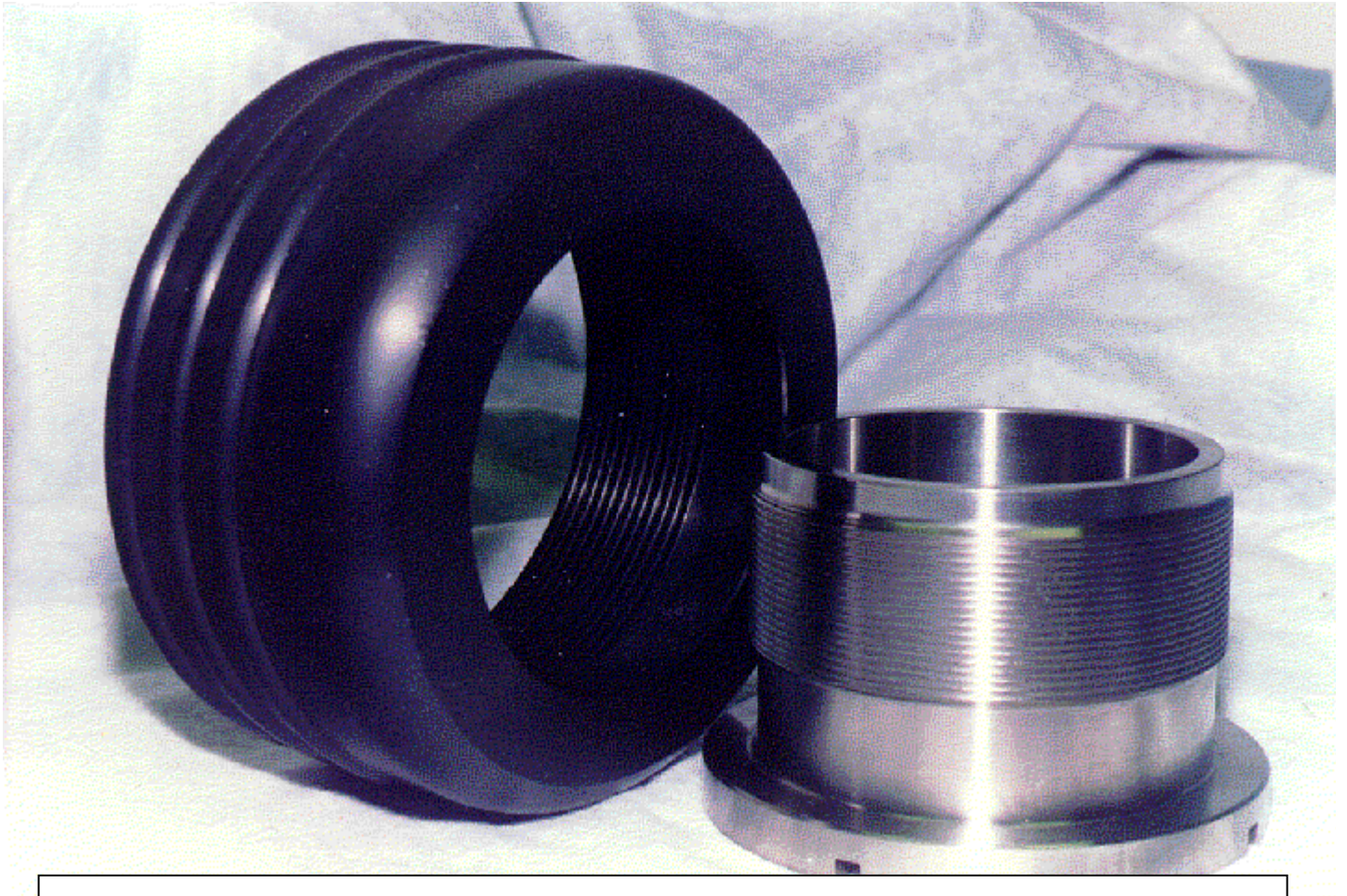


Figure 8 -- Fully Integrated Carrier/Seal Design