Technical Report

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VAM®21, an Innovative High-performance Premium Threaded Connection for OCTG

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Abstract

The Oil & Gas industry's increased activity in HPHT and deepwater well developments requires high strength and excellent seal integrity to withstand high pressure, high temperature and high combined loads like as external pressure and compression on threaded connections for Oil Country Tubular Goods (OCTG). "VAM®21" is developed as an innovative high-performance premium threaded connection which has high strength and high seal integrity to comply with the severest protocol of ISO13679 CAL IV, within the full pipe body envelope, and excellent handling and running ability on the actual rig site than conventional products. The development was carried out by using Finite Element Analysis (FEA) and physical prototype testing, and the strength and seal integrity of all production sizes was validated based on the product line approach. Regarding the handling and running ability, the excellent performance was proved with a lot of rig tests at many testing rig sites around the world.

1. Introduction

With the decrease in easily exploitable crude oil and natural gas in recent years, it has become necessary for oil and gas wells to go deeper underground and underwater. Since these wells are subject to high pressures and high temperatures (HPHT), threaded connections used to connect the OCTG pipes must have exceptionally high strength and sealing integrity, and especially high resistance to compressive loads and sealing integrity against external pressures. Furthermore, if the stabbing performance of threaded connections (described later) is poor, running work cannot be efficiently conducted in the field. Poor stabbing performance can also cause a scratch or galling on the thread and sealing surfaces. In the worst case, the OCTG pipe itself must be replaced, seriously impeding well completion work. Thus, handling and running ability are also out of the most important requirements for threaded connections.

In addition to the standard threaded connections for OCTG [1] specified by the American Petroleum Institute (API), various high-performance premium threaded connections have been developed and sold by a lot of manufacturers.[2, 3] The market requirements for the performance of threaded connections have become increasingly severe every year. ISO 13679 [4] (international standard testing procedures for threaded connections for OCTG) was published in 2002. In those days, however, there were very few high-performance premium threaded connections for OCTG that complied with the severest testing protocol CAL IV, within the full pipe body yield stress envelope.

To meet the severe market requirements mentioned above, Nippon Steel & Sumitomo Metal Corporation developed a high-performance premium threaded connection, VAM®21, which is far superior to conventional products in its resistance to compression and sealing integrity against external pressure, its high strength and sealing integrity that perfectly complies with the severest protocol CAL IV of ISO 13679 even within the full pipe body yield stress envelope, and its handling and running ability at the rig site improved drastically.[5] Developed as a standard product line, VAM®21 is now available in 55 different sizes: from 5 to 14 inches. It is applicable not only for the pipes of carbon steels and high-strength sour-resisting steels specified in ISO11960 (API 5CT), but also for pipes made from ISO 13680-compatible, high-alloy steels of Nippon Steel & Sumitomo Metal.

In this report, we shall describe how the high-performance premium threaded connection, VAM®21, was developed and how its

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excellent performance properties were verified.

In the first stage of development, prototypes of a representative size were subjected to testing and finite element analysis (FEA), and basic design concepts, such as the nose and taper guide (described later), were developed. In the second development stage, the said basic design concepts were extended to all production sizes, and the design of each individual size was optimized. Next, the performance of each of the different sizes was confirmed on the basis of the concept of product line approach. In the final development stage, many running tests (rig tests) were carried out at various training rig sites around the world to verify VAM®21's excellent performance for handling, make-up, and break-out.

2. Features of the High-Performance Premium Threaded Connection VAM®21

2.1 Sealing mechanism characteristics

As shown in **Fig. 1**, many conventional premium threaded connections for OCTG have not only a tapered thread but also an unthreaded sealing surface, called a metal-to-metal seal, to enhance sealability. They also have a torque shoulder, which is a stopper of make-up for properly controlling the generated stress and seal contact. The male part ("pin") of the metal-to-metal seal is slightly larger in diameter than the female part ("box"). The difference in seal diameter between the pin and the box shall hereinafter be referred to as the interference. The sealing integrity is produced by the elastic recovery force, which is induced by the interfering contact.

In the case of an conventional premium threaded connection, a seal is provided around the tip of the pin, and the pin end surface forms a torque shoulder, as shown in **Fig. 2** (a). Upon completion of the make-up, the pin torque shoulder abuts against the box torque shoulder and the radial component of the reaction force increases sealing contact on seal. With such a sealing mechanism, however, sealing integrity may be adversely affected when a large tensile load is applied to the connection, or when a compressive load is repeatedly applied to the connection and the torque shoulder is subjected to serious plastic deformation. In particular, if the torque shoulder fails to increase sealing integrity when a high-pressure fluid penetrates into the connection from outside and reaches the metal-to-metal seal through the thread gap, it is highly possible that an external pressure leak will occur, with fluid penetrating into the OCTG pipe interior beyond the seal.

On the other hand, the high-performance premium threaded connection, VAM®21, is characterized by a pin extension, called a nose, and a stabilizer at the tip of the nose, as shown in Fig. 2 (b). Characteristically, the nose amplifies the seal contact force by utilizing its own stiffness, rather than a reaction force produced when the torque shoulder abutment. In other words, the force of elastic recovery, by which the pin seal surface diametrically reduced by the interference exhibits a tendency to return to its original diameter, is amplified by the stiffness of the adjoining nose. Since this amplifying effect is stably achieved regardless of torque shoulder contact, the connection maintains high sealing integrity even when it is repeatedly subjected to a large load.

Another characteristic of the new sealing mechanism is the stabilizer structure. As shown in Fig. 2 (b), the stabilizer consists of a negative-angled torque shoulder at the pin end, and taper guide 1, which is adjacent from the torque shoulder. Thanks to this structure, radial deformation of the nose even under a large compressive load is restrained and compressive deformation of the nose is stabilized. As a result, stabilizing the sealing integrity of the adjoining metal-to-metal seal under a compressive load is possible. Notably, taper guide 1 is very similar in shape to the seal of a conventional product, but it does not function as a seal because its surface has a groove for releasing trapped lubricant pressure.

In the new VAM®21 seal structure, the seal surface comes inside the line connecting the male thread crest with taper guide 1, as shown in **Fig. 3** (a). This helps prevent the seal surface from being

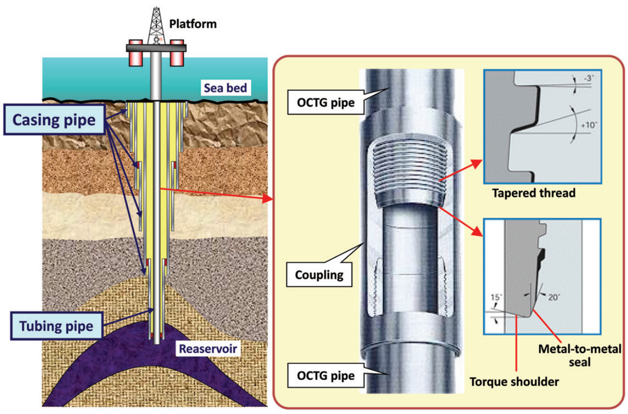

Fig. 1 Schematic of typical well string design and premium connection

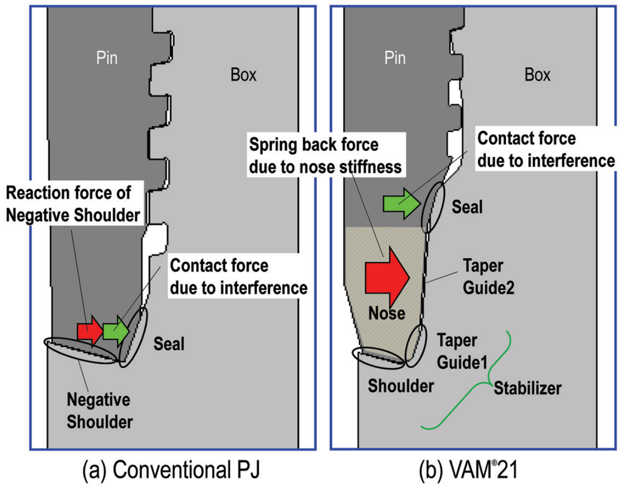

Fig. 2 Feature of sealing structure and mechanism

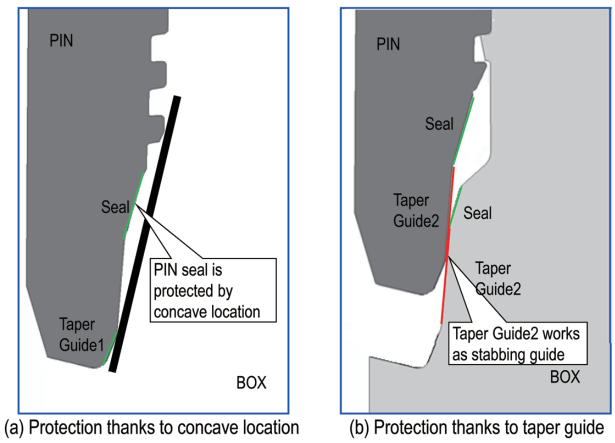

Fig. 3 Schematic of seal surface protection

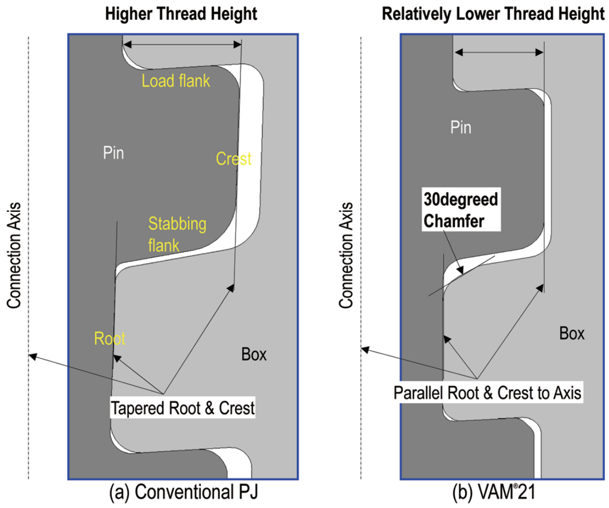

Fig. 4 Feature of thread shape

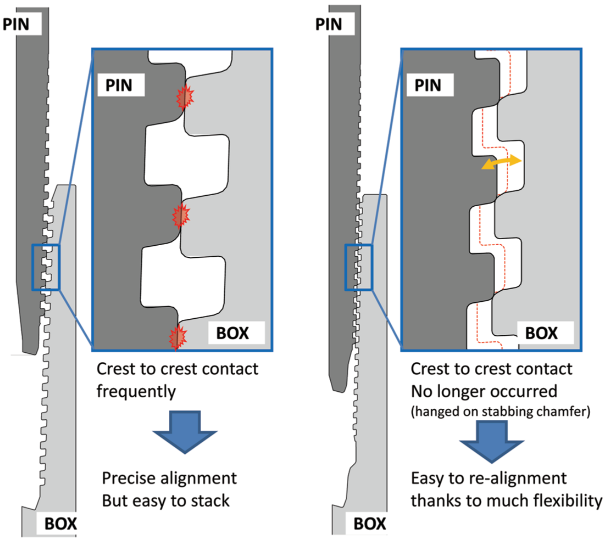

Fig. 5 Improving mechanism for stabbing performance

damaged during running in the rig. In addition, the two taper guide surfaces between the seal and torque shoulder (shown in Fig. 3 (b)) work as the stabbing guides, which help prevent the seal surface from being damaged during make-up.

2.2 Thread characteristics

Figure 4 compares the thread profile of VAM®21 with that of a conventional premium threaded connection. Many conventional premium threaded connections, including API buttress threads, have a thread form whose root and crest are parallel with the thread taper. By contrast, VAM®21 is given a trapezoidal thread form whose root and crest are parallel with the connection axis, as shown in Fig. 4 (b), to enhance the ease of make-up, especially stabbing performance. The term "stabbing performance" as used here implies a performance whereby the connection pin is required to be fully inserted into the box smoothly, without causing a cross-threading or stacking, so that pin turning can be started immediately after insertion.

In the case of VAM®21, the thread root and crest are parallel with the connection axis, as shown in Fig. 4 (b). Therefore, even when there is a misalignment between the pin and the box, as shown in **Fig. 5**, the pin and box are easily realigned and the pin can be readily inserted into the box without causing a cross-threading or stacking or other similar problems that tend to occur with conventional connections. In addition, the chamfer given to the stabbing flank of female thread helps reduce galling-causing damage that can occur when the corner of the stabbing flank is subjected to a strong impact during stabbing.

3. Testing and Finite Element Analysis Procedures Used for Development

3.1 Physical test procedure

During the development of the new premium threaded connection, our ultimate aim was to completely comply with the CAL IV protocol of the ISO 13679 Test Standard for all production sizes of the new product. During tests based on the CAL IV protocol, eight samples prepared for each size/grade are subjected to the prescribed adjustment of dimensional tolerances and are tested under the prescribed cyclic combined loads, as shown in **Fig. 6**. Including the preparatory work, the testing consumes much time and resources.

As described later, the present development was carried out using the product line approach based on a consistent design concept. Namely, most representative dimensions (outside diameter/wall thickness) of the prepared samples were tested on the basis of the full version of the CAL IV test protocol, whereas the other dimensions of the prepared samples were tested either in accordance with the condensed version of the CAL IV test protocol (which is as severe as the full version), or subjected to the FEA described later.

In addition, to evaluate the galling resistance of the connection, samples varying in size, material grade, and surface treatment were subjected to a so-called make-up & break-out test (M&B test), in which they were made up and broken out repeatedly. Ordinarily, short-pipe samples approximately 1 m in length are used in a M&B test. However, since actual OCTG pipes are as long as approximately 10 m, such a test does not always simulate actual thread contact conditions. Therefore, we supplemented the above test with (i) another M&B test using a dead weight that was equivalent to the weight of an actual OCTG pipe, and (ii) a rig test using long OCTG pipes.

The rig test purpose was not limited to evaluating the stabbing performance and galling resistance of threaded connections. Since a rig test subjects actual OCTG pipes to ambient conditions nearly the same as those of actual wells, it could be used to verify the advantages of the newly developed threaded connection in such a rigorous operating environment.

In addition to the above tests, various types of failure tests, including a tension to failure test, were carried out to verify the ultimate failure mode of the connection when a load exceeding the tensile strength of the OCTG pipe material was applied.

3.2 Finite element analysis (FEA) procedure

During the development of VAM®21, an elasto-plastic FEA was applied during all stages of development: from the study of basic design concepts and production size extension to the evaluation of sealability for all sizes in the final design. For the analysis, ABAQUS/Standard—named commercial software for FEA—was used. In most cases, the purpose of FEA is to evaluate the sealability (contact conditions on a seal surface) of axisymmetric body. For that purpose, the analysis used a two-dimensional axisymmetric model with the spiral of thread left out of consideration (see **Fig. 7**). The threaded connection make-up was simulated using the following

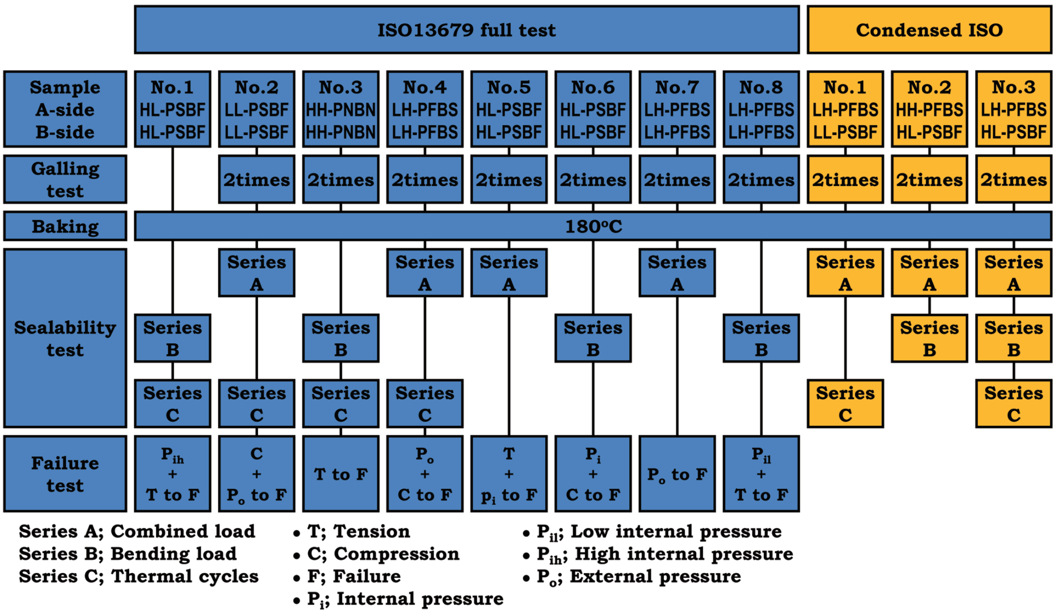

Fig. 6 Physical test flow of ISO 13679 CAL IV used in this development

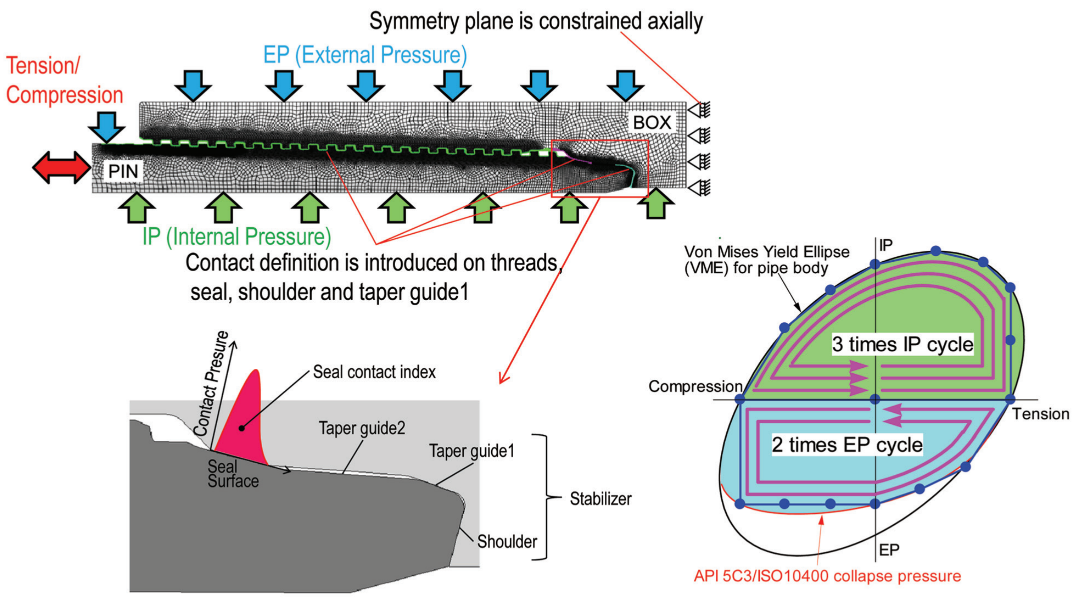

Fig. 7 Schematic of FEA model, sealability parameter and loading condition

procedure. First, the finite element meshes of the thread and seal surface were geometrically overlapped by the amount corresponding to the interference. In the analysis process, the overlap was resolved to simulate fitting conditions for thread and seal surface. Next, using one of the ABAQUS analytical functions (the function of introducing a pretension), a specific part between the thread and torque shoulder was axially extended during the analysis process to simulate the condition of a torque shoulder being abutted with the prescribed torque.

In almost all of the FEA evaluations for sealability, a loading sequence simulating the Series A Test in CAL IV Protocol of the ISO 13679 Test Standard was applied. The connection models were subjected to various combined loads of tensions/compressions along the connection axis, and internal/external pressure in the manner on the ellipse of Von Mises yield stress, as shown in Fig. 7. Considering the pressure penetration into the seal surface, when the seal contact surface opened during the analytical process, the prescribed pressure load was applied incrementally to the newly exposed seal surface as well.

In the analysis, sealability was evaluated in terms of a seal contact index representing normalized seal contact force per unit circumferential length. In other words, the seal contact index is the result of the integration of contact pressures along the seal longitudinal section surface shown in Fig. 7, and is equivalent to the area under the line showing seal contact pressure distribution. Since this index is free from the influence of seal surface circumferential length (i.e., the outside diameter of the OCTG pipe), it can easily be used to compare sealability among threaded connections of different siz-

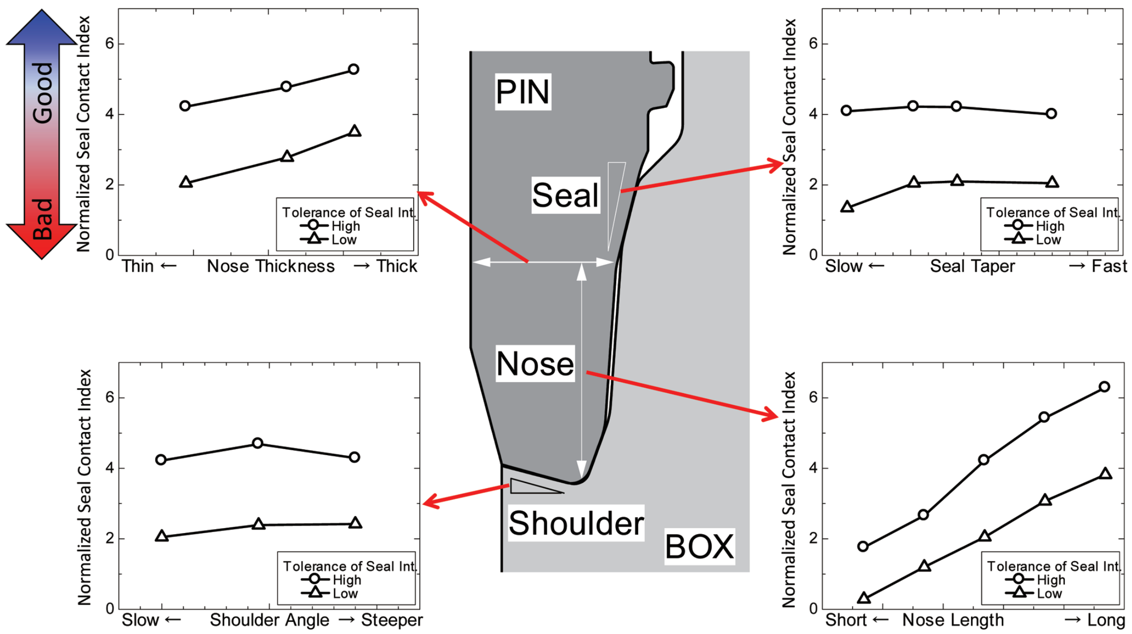

Fig. 8 Relationship between normalized seal contact index and seal design factor

es. The seal contact index is considered to show the magnitude of margin for leakage. With this index alone, therefore, it is impossible to judge the absolute sealability, i.e., whether or not there is leakage. Nevertheless, the index is very useful when it comes to making a relative comparison of the margin of sealability between different concepts, or detecting the product size for which the margin of sealability will be the smallest. For the present development, FEA was carried out for all product sizes that were subjected to the final design, whereas all sizes for which the margin of sealability was found to be small were subjected to a physical test. The results confirmed that all sizes were free of leakage.

4. Study for Designing New Seal Structure

With regard to the new seal structure for the VAM®21, we conducted a fully extensive study covering inspiring conception, design optimization, size extension, and final design. In this chapter, several studied matters shall be described.

First, for the purpose of design optimization, we used FEA to evaluate the influence of each seal design factor on sealability against external pressure. The analysis of representative product sizes described in Chapter 3.2 evaluated the influence of each of the four seal design factors (shown in **Fig. 8**) on sealability against external pressure (i.e., the minimum value for the seal contact index in an external pressure loading process that simulates Series A Test on the basis of the ISO 13679 Test Standard). The analysis results are also shown in Fig. 8. It can be seen that the influences of nose thickness and nose length are especially significant; i.e., the thicker and longer the nose, the larger is the minimum value of the seal contact index (the better is the sealability against external pressure).

Of the two design factors that significantly influence sealability against external pressure, nose thickness was maximized for each individual wall thickness by optimizing the thread taper and the thread height of the threaded part that share the wall thickness. Excessively long nose make the overall connection length much longer, so that it would affect unexpectedly to the handling ability and

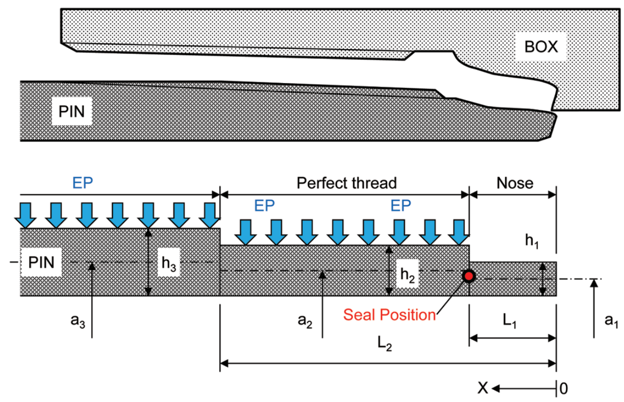

Fig. 9 Elastic cylindrical shell model for pin under EP

the productivity. Therefore, using the elastic cylindrical shell theory, we optimized the nose length for each of the outside diameters and wall thicknesses. Specifically, on the assumption that the pin was an elastic cylindrical shell varying in thickness, as shown in **Fig. 9**, we obtained the relation between nose length and seal diameter shrinkage when the pure external pressure prescribed in API BUL 5C3 [6] was applied to the outer surface of the pin except in the nose. It can be seen from **Fig. 10** the shrinkage of seal diameter saturates when the nose reaches a certain length, although it decreases with an increase in nose length. This implies that the longer nose has a limited effect in improving nose stiffness. For the design of all production sizes described later, we optimized the nose length for each of those sizes, on the basis of study results obtained through the elastic shell theory.

5. Verification of Performance for Production Sizes

5.1 Guarantee of performance based on product line approach

The new premium threaded connection, VAM®21, was developed as a so-called product-line item available in many different

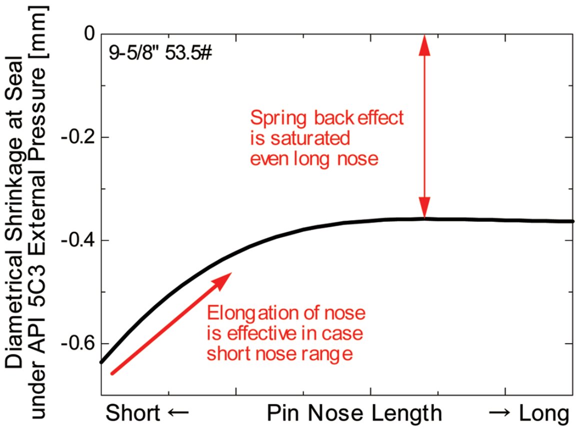

Fig. 10 Estimation result of pin lip shrinkage by the elastic cylindrical shell model

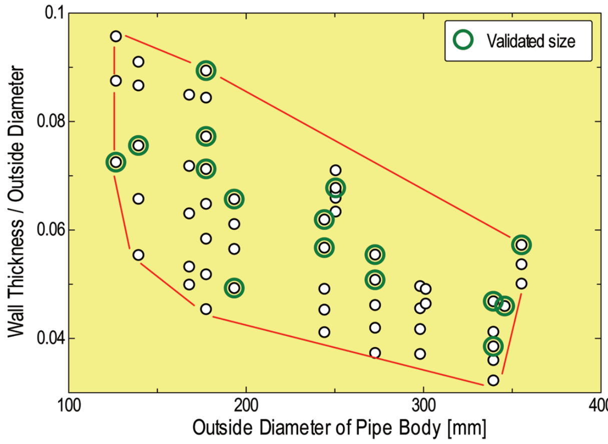

Fig. 11 M&B test results for verification of galling resistance

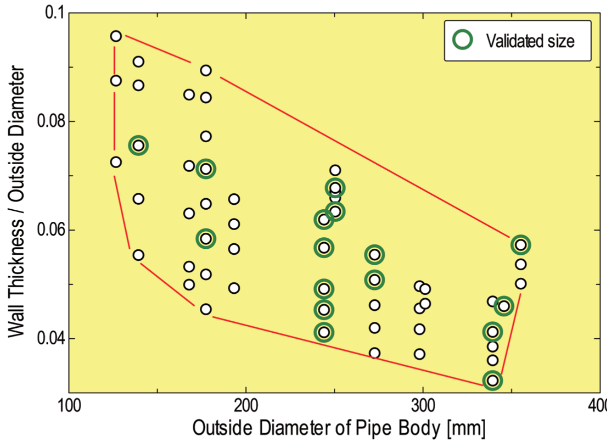

Fig. 12 Tension to failure test results for verification of failure mode

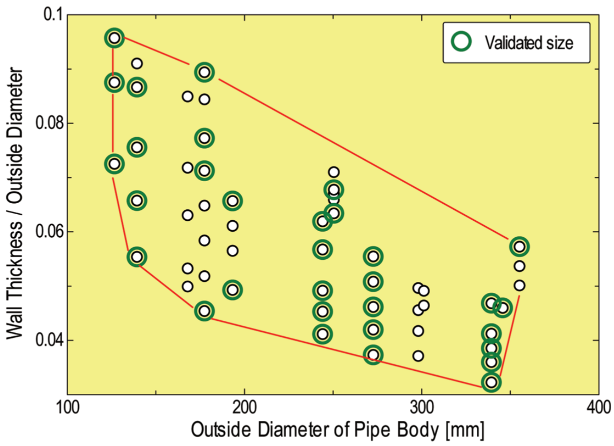

Fig. 13 Sealability test results

sizes. When extending the basic design concept described earlier to the many production sizes (from 5 to 14 inches), we verified the performance of all sizes on the basis of product line approach. The product line approach is a technique applied to a polygon covering all production sizes on the matrix of outside diameters and wall thicknesses of OCTG pipes; i.e., all important sizes, including the corner sizes of the said polygon, common commercial sizes, and critical sizes detected by FEA, are subject to physical testing for performance verification specified in the full or condensed version of the CAL IV protocol, whereas the performances of rest (remaining) sizes are subject to an FEA-based interpolation for verification.

Figure 11 shows a matrix of sizes which were verified, during M&B tests, to have sufficient galling resistance. The galling resistance of each size was basically verified using carbon steel, taking the largest wall thickness for each outside diameter that was considered to be the most critical in terms of galling. For the principal sizes, galling resistance was also verified using some high-alloy steels of Nippon Steel & Sumitomo Metal, such as 13Cr steel, Super-13Cr steel, and austenitic stainless steel. **Figure 12** shows the sizes for which the ultimate failure mode was confirmed through tension to failure tests. For all tested sizes, it was confirmed that the ultimate failure mode was not a jump-out, but a rupture at the pipe body or pin imperfect thread.

Figure 13 shows the sizes for which sealability was verified by the sealability tests specified in the full or condensed version of the CAL IV Protocol of the ISO 13679 Test Standard. For all polygon corner sizes, major product sizes, and critical sizes identified by FEA, no leaks occurred during the sealability test specified by the CAL IV Protocol of the ISO 13679 Test Standard. As shown in **Fig. 14**, the sealability for all product-line sizes was also evaluated by FEA. It was verified that sizes not subjected to the above-mentioned physical test exhibited a larger value of seal contact index than sizes subjected to the physical test. The above study results verified that all production sizes of our new premium threaded connection, VAM®21, comply with the CAL IV Protocol of the ISO 13679 Test Standard.

5.2 Verification of running ability by rig tests

To verify handling and running ability at oil wells, many rig tests were carried out. Using Range 3 samples (approximately 12 meter in length) of three different sizes, as shown in **Fig. 15**, we carried out many M&B tests at various training rig sites around the world. During each rig test, the sample was lifted by a side-door type elevator, the pin at the OCTG pipe end was inserted into the box fixed onto the platform, and make-up was conducted with the pin stabbed into the box and the entire weight of the OCTG pipe applied to the connection. During the above-mentioned rig tests at various training rig sites around the world, all of the samples were free from galling, cross-threading, and stacking. While the ISO 13679 Test Standard requires that M&B tests shall be carried out twice for each sample, each of our samples successfully underwent their own tests five times or more. Through these rig tests, we demonstrated that the newly developed VAM®21 significantly enhances the running ability.

5.3 Examples of applications at customer sites

As one of the world's foremost threaded connections, VAM®21 is being shipped in growing numbers to areas such as the North Sea, Southeast Asia, the Middle East, West Australia, and Brazil (see **Fig. 16**). It is expected that the product will facilitate worldwide development of deep underground or deepwater wells exceeding 4,000 m in depth, and will help increase the production of conventional natural gas, which is found deeper than crude oil resources located underground or underwater.

6. Conclusion

We developed VAM®21, a new, high-performance premium threaded connection for OCTG, to assist in the exploitation of exceptionally deep oil/gas wells that are subject to high temperatures and high pressures. This report describes the product technology and development activities that made it possible to develop the VAM®21. The VAM®21 complies with the CAL IV Protocol of the ISO 13679 Test Standard under a load condition equivalent to the yield strength of the pipe body, and it significantly enhances the handling and running ability in the field. The combination of a nose and a stabilizer at the pin tip has dramatically improved sealability against external pressure and compression resistance. The basic design concept was extended to 55 different product sizes, ranging from 5 to 14 inches. For all production sizes, sealability, galling resistance, and ultimate failure mode were evaluated and verified by physical testing and FEA on the basis of the concept of product line approach. In addition, a new thread form was adopted to improve stabbing performance. The excellent handling and the efficient running ability in the field were verified during many rig tests. The new product has already been shipped to various areas of the world, and is being applied to many deep underground and deepwater wells that would be difficult to exploit with a conventional product. We intend to further expand the product lineup in order to fully meet the requirements of an increasingly diversified market, and increasingly

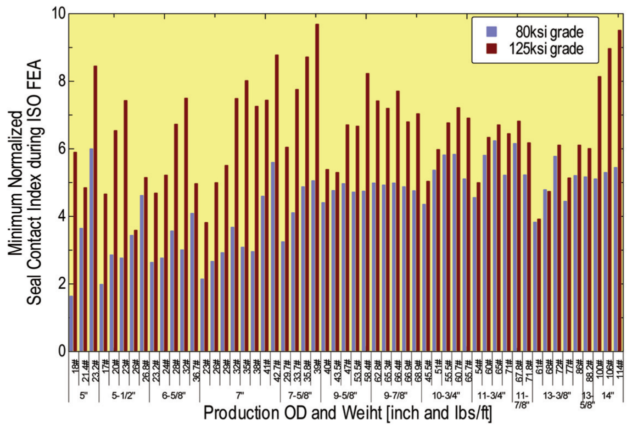

Fig. 14 Sealability verification results by FEA

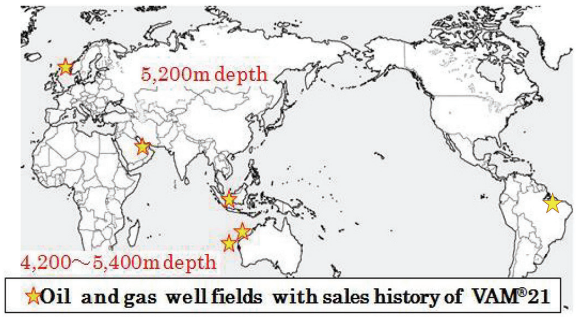

Fig. 16 Oil and gas well fields with sales history of VAM®21

Test Rig Site	Size	Grade	Connection	M&B success	Remarks
Pau	9-5/8"	P110	VAM® 21	5 times	
Houston	13-3/8" 72#	Q125	VAM® 21	5 times	
			Conventional Connection	more than 2 times	
Nagaoka			VAM® 21	5 times	
Houma	10-3/4" 65.7#	L80-13Cr	VAM® 21	5 times	
			Conventional Connection	5 times	
Aberdeen	10-3/4" 65.7#	L80-13Cr	VAM® 21	5 times	
			Conventional Connection	4 times	Cross thread

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Fig. 15 Rig test results

sophisticated customer needs.

Acknowledgments

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