LOCK RINGS on OCTG tubulars in Oil Field applications: RP/2014 Eng. Jan - 002

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A study into the use of locking rings on OCTG pipes versus the alternative use of bonding of Rubber based Rings on to OCTG pipes.

The Effect of Temperature on Locking of Rings on OCTG pipes.

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Pre-Amble

Within the Oil world it is an accepted common practise to use grub screw type locking rings or on swelling seals, grub screw locking running guides to hold items in place during running into Oil or Gas wells. This practise is many years old and is widely accepted in Oil field applications as a means to attach items such as centralisers, collars etc. onto Tubular goods. With the more widely accepted use of bonded swelling elastomers on Oil Field Tubular this has led to a system where the seals are bonded to the tubular and then a running guide made of steel is placed onto the tubing and locked into place with grub screws.

This study is looking into this latter application reviewing its usage along with advantages and disadvantages as well as indicating potential acceptable alternatives to this.

1.0 OCTG Tubing

Dimensions of OCTG are laid down in both API and ISO specifications. The tolerances used on both the pipe OD as well as the tubing weight per foot determine what effectively the outer and Inner dimensions are. For the purpose of this study the important dimensions are the Outside Diameter of the tubular and with it the manufacturing tolerance on this. In this study we only look to those of the 4,5 inch tubular.

Maximum OD	**4,545**	**Inch**	**115,443**	**mm**
Nominal OD	**4,5**	**Inch**	**114,3**	**mm**
Minimum OD	**4,4775**	**Inch**	**113,7285**	**mm**

Fig 1.

The dimensions in Fig 1 give both the maximum and minimum dimensions as well as the tolerance on ovality. Because of these tolerances a wider dimension on the ID has to be applied to any slip on ring needed to be fitted. This would commonly be in the order of 117 mm with a tolerance of +/- 0,1mm.

		117 mm		117,1 mm		116,9 mm	
115,443	**mm**	**1,557**	**mm**	**1,657**	**mm**	**1,457**	**mm**
114,3	**mm**	**2,7**	**mm**	**2,8**	**mm**	**2,6**	**mm**
113,7285	**mm**	**3,2715**	**mm**	**3,3715**	**mm**	**3,1715**	**mm**

Fig 2.

Fig 2 shows how the dimensions affect the space between the “slip on” ring and the pipe depending upon the tubular and ring tolerances used.

The Slip on ring tolerance is created because of the effect that mill scale and mill varnish drops have on the ability to slip the ring onto the pipe for any distance. Care has also to be taken that when the slip on ring is fitted that it is reasonably well centred. If poorly centred then it can give an off centre diameter with the production tolerances that would give:-

Ring Thickness **maximum Pipe OD**	**115,433**	**mm**
Maximum Ring ID	**117,1**	**mm**
Ring thickness	**20**	**mm**
Centered OD	**155,433**	**mm**
Off Centered OD	**157,09**	**mm**

Fig 3.

These are one of the important to be aware of in close tolerance work because with two guide rings at opposite extremes and a not too straight a pipe that they can cause potential running in problems and even lead to hang ups.

2.0 Thermal Expansion:

All dimensions as above are based upon normal temperature commonly 18-20 Celsius. However in the well temperatures change and can increase dramatically. Increases of 100 Celsius are common and as technology develops even 150 Celsius is not impossible. This can have a substantial effect on slip on rings. In these situations the pipe will expand and the slip on ring too. This effect however is very much dependent upon the metallurgy combination of the pipe and the slip on ring.

	10^{-6} m/m K
Brass	18,7
Cast Iron Gray	10,8
Copper	16,6
Gunmetal	18
Hastelloy C	11,3
Inconel	12,6
Iron, cast	10,4
Iron, forged	11,3
Iron, pure	12
Monel	13,5
Nickel	13
Phosphor bronze	16,7
Rubber, hard	77
Steel	***13***
Steel AISI 4140	***12,2***
Steel Stainless Austenitic (304)	***17,3***
Steel Stainless Austenitic (310)	***14,4***
Steel Stainless Austenitic (316)	***16***
Steel Stainless Ferritic (410/420)	***9,9/10,5***

Fig 4.

In the list in Fig 4. If only the last 6 are used as an example, the results can be quiet substantial. For example in the worst of these SS 304, the expansion coefficient is 75% higher than SS 410. This is important because if we were to have a SS410 Tubular (read 13Cr) and fit a SS 304 or SS316 slip on ring then as it warms up, it will expand, however the SS410 expands less that the SS304/316 would. The grub screws holding the Ring on the tubular will also expand but because they are only extend a very short distance out of the ring they do not expand as much. The result of this is that the holding force locking the ring to the tubular decreases.

It is worth noting that in the above example that if the pipe is a Steel one that is using a SS410 ring would probably result in an increase locking force as the Pipe would expand more than the ring.

In most instances Stainless steel sorts are used as a corrosion resistance to well fluids. It is therefore important to review the metallurgies used in the Slip on Lock Ring and the Tubular. Also bear in mind that the value of coefficient of expansion alters (read increases) with increased temperature. For 420 in the Fig 4. The Coefficient is 10,5 at 100 Celsius and 11 at 200 Celsius.

In the above, metallurgy brings with it a dilemma in that whilst some control over potential choice is possible, often the actual choice is determined by the availability of metal sorts in the shape available. Things like availability of bar or pipe stock raw material are important factors which influence and determine the engineering choices available.

Results of Expansion

Steel Pipe with Steel Ring

Expansion Coefficient							
Steel	13	0,000013					
Ring		Circumference	20	75	100	150	200
ID	117	367,5663405	367,6619	367,9247	368,0442	368,2831	368,522
			0,095567	0,358377	0,477836	0,716754	0,955672
New ID			117,0304	117,1141	117,1521	117,2282	117,3042
Expansion Coefficient							
Steel	13	0,000013					
		Circumference	20	75	100	150	200
OD	114,3	359,0840403	359,1774	359,4341	359,5508	359,7843	360,0177
			0,093362	0,350107	0,466809	0,700214	0,933619
New ID			114,3297	114,4114	114,4486	114,5229	114,5972
			20	75	100	150	200
Increase in Room		0,006318 mm	2,700702	2,702632	2,70351	2,705265	2,70702
Lock Ring ID							
Steel							
Coeffeicient of Expansion	0,000013	10-6 m/m K					
ID	117						
Pipe OD							
Steel	0,000013	10-6 m/m K					
OD	114,3						

13Cr Pipe with SS304 Ring

Expansion Coefficient							
SS Austenitic (304)	17,3	0,0000173					
Ring		Circumference	20	75	100	150	200
ID	117	367,5663405	367,6935	368,0433	368,2022	368,5202	368,8381
			0,127178	0,476917	0,63589	0,953835	1,27178
New ID			117,0405	117,1518	117,2024	117,3036	117,4048
Expansion Coefficient							
SS Ferritic (410)	9,9	0,0000099					
		Circumference	20	75	100	150	200
OD	114,3	359,0840403	359,1551	359,3507	359,4395	359,6173	359,795
			0,071099	0,26662	0,355493	0,53324	0,710986
New ID			114,3226	114,3849	114,4132	114,4697	114,5263
			20	75	100	150	200
Increase in Room		0,160655 mm	2,717851	2,76694	2,789253	2,83388	2,878506
Lock Ring ID							
SS Austenitic (304)							
Coefficient of Expansion	1,73E-05	10-6 m/m K					
ID	117						
Pipe OD							
SS Ferritic (410)	9,9E-06	10-6 m/m K					
OD	114,3						

Whilst the results do not at first sight seem to be that much the results in potential holding force are.

3.0 Use of Running Guides.

The crucial element in this is what is the actual function of the running guide and what effect the temperature would have on their actual function rather than just on their mechanical properties.

What is understood by the term running guide?

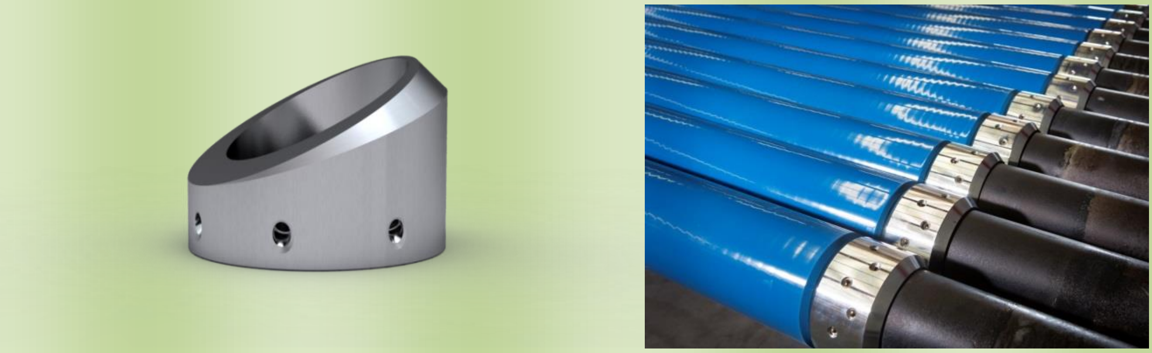

Fig 5.

Running Guides are the shining metal rings seen in Fig 5. Their actual physical function is not always as clear as their claimed function. In the original units that we supplied in 2000-2001 for the original Oil Swell Test Packer they were intended to act as elastomer protection as we did not have experience on the ability of swelling elastomer to resist damage and abuse while being run into wells. These original packers physical form has formed the basic design that now all manufacturers supply to the fracture seal market. Under the idea that if it worked for them it will work for me type of engineering. These designs are commonly described as being the MEE2 seals, where one has copied the other to be able to follow another supplier into the same market.

Primary Function

The often stated function of a slip on protection needs to be viewed against not what it is supposed to do but what it *can* actually do. In the protection role we need to understand what the elastomer actually is doing when the unit is being installed as it is the installation that would result in damage rather than when it has reached its intended depth. While the swell elastomer seal is being run into the ground three things happen to it.

- It warms up and expands
- Its starts to undergo swelling
- It is subjected to hydrostatic pressure.

In the first the coefficient of thermal expansion is (See Fig 4) between 4 and 8 times greater than the metallurgies of the locking rings. This means that to protect the elastomer the running guide would have to have dimensions greater that the elastomer at surface, just to compensate for expansion caused by heating up.

In the second the diffusion of Motive Fluids will cause the elastomer to swell, again increasing its diameter relative to the running guide.

In the third the hydrostatic pressure will build up (Hydrostatic Pressure = ρ x g x h. Where rho (ρ) is the fluid density, “g” is the gravity and “h” is the column height. Note in wells “h” is defined as TVD (True Vertical Depth) as opposed to AH (Along Hole) and is often combined with a reference point where this is taken from such as ORT (Original Rotary Table). This ORT refers to the drill floor height above ground or above sea level used when drilling the well.) As the pressure builds up there is a small potential effect on the diameter caused by the compressibility of the elastomer. This works to make the actual OD of the elastomer very slightly smaller.

With all of the above it is debateable as to whether the attributed function in most instances is real. Outside of the claims made of them our experience has been gained from packers run in Oman and then due to well issues removed from the well before the swell packer had set. In these cases elastomer (which was run without any form of metallic running guides) showed no signs of damage at all. In the original tests in Oman the seals (short 400 mm sections) were alternated with hard abrasive resistant elastomer. Original tests indicated that they had no beneficial effect at all and this practise was dropped.

To understand the ability of rubber versus metal to withstand wear and to prove or disprove the potential of running guides to protect a series of spate tests have been conducted looking into grub screw shape, angles and numbers of the grub screws for holding forces, wear through abrasion of Elastomer and Metal, bonding forces and bonding.

Secondary Function

If the primary function of the running guide is the protection of the elastomer during running into the well its secondary function is often stated to be one of anti-extrusion of the swelling seal. However care needs to be taken with this comment. As Elastomer actually a super viscous fluid it will under pressure flow and be forced or to creep out of a space it fills. However on non-swelling elastomer extrusion only occurs on the Low Pressure side of the seal as the differential pressure causes it to creep effectively out.

Our own testing has shown that swelling elastomer rides over the running guide on both the high pressure and the low pressure side of the seal. This indicates that this is not extrusion related event, but a swelling related one and that this is causing the effects being attributed to extrusion. Testing indicates to us that this swelling could actually be the physical result of the use of these running guides. To expand on this, swell in Elastomers is isotropic which means in normal circumstances it swells in all directions for the same unit dimension the same amount. This means that because the longest unit is one of length its swell in absolute values the most in the length direction. However in practise two things happen.

- Because it is bonded to a piece of pipe the bond restrains the increase in length caused by swelling. (it is worth noting that the longer the seal the greater is the stress on the bonding caused by swelling length increase so seals should always be as short as possible)
- With open ends the ends swell quicker than other parts due to their having a larger surface to volume ratio.

This means that when the elastomer swells the ends exposed to fluid get thicker quicker than the middle section, this effectively sealing the centre section off from more fresh motive fluid. In a water swell application the centre section will still continue to swell using the trapped fluid. However because the water for swelling is being extracted as pure water from this trapped fluid brine the salinity of this remaining brine increases quickly and swelling now in the centre slows down and reduces and in some cases eventually stops. This is because the trapped fluid becomes too saline and can if the elastomer is not designed to swell in saturated brines gives a limit to middle swell and with it to the increase in length caused by swell increase.

However in an application fitted with running guides there are two potential configurations, commonly in the MEE2 type seals they are placed hard against the elastomer ends as this was what was used for Oil Swell Applications where the swelling is different. However in water swell after a small limited swell to fill any void between the elastomer end and the running guide, free swelling of the end effectively stops. As there is no longer the same volume to surface ration at the end they swell just as quickly at the ends as in the middle. This has the effect that the swell in the centre section is the same as the ends and as such is no longer constrained by trapped brine and the increase of trapped water salinity but only by its ability to swell out to the sealing surfaces.

In the second configuration which is what we use and advocate the running guide is placed a short distance from the end of the elastomer this allows the ends to initially swell quicker and more before they contact the running guides and end swelling stop being unrestrained. This has the effect of creating a trapped space in the seal and reducing the length swell increase.

Wear Resistance

One of the primary supports for the use of metallic running guides is an often claimed better wear resistance when running into the well. To look into this and quantify and substantiate this a series of tests were conducted using an ISO wear resistance test as outlined in **ISO 4649** - *Rubber, vulcanized or thermoplastic Determination of abrasion resistance using a rotating cylindrical drum device.*

Tests were run with both Elastomers and Steel to calculate for comparison the wear that both would be subjected to. The results indicate that while steel has a clearly better wear resistance to rubber that this is far less than most would expect or imagine it to be. Also it needs to be born in mind that the figures obtained from this test were for a DRY situations. In fluid lubricated situations this is an absolute value that would be considerably lower than in dry situations. However we believe the same rough ratio would apply, the absolute value would only be much lower.

Compound	Sample	Abrasion Weight Difference (mg)	mm3/mm	Factor Wear to steel
405-70	1	85,4	72,99	3,45
405-70	2	88	75,21	3,55
405-70	3	94,3	80,60	3,81
average			76,27	**3,60**
405-70	1	101,3	87,33	4,13
405-70	2	92,7	79,91	3,78
405-70	3	99,8	86,03	4,07
average			84,43	**3,99**
1552-70	1	136	108,80	5,14
1552-70	2	150,4	120,32	5,69
1552-70	3	161,5	129,20	6,11
average			119,44	**5,64**
St52	1	166,1	21,16	**1,00**

In looking at wear it should be born in mind that the load bearing surface also has an impact, that's not only in terms of the smoothness/roughness but also the length of this contact surface, If the swelling seal is 6 ft. or 10 ft. long this has a larger effect of the whole as opposed to 4 or 5 inches for each running guides.

Coefficient of Friction

The biggest cause of wear on friction between different articles is the coefficient of Friction. In this brief table an indication of the differences of coefficient of friction can be seen.

MATERIAL 1	MATERIAL 2	Coefficient Of Friction			
		Dry		Greasy	
		Static	Sliding	Static	Sliding
Rubber	Asphalt (Dry)		0.5-0.8		
Rubber	Asphalt (Wet)		0.25-0.75		
Rubber	Concrete (Dry)		0.6-0.85		
Rubber	Concrete (Wet)		0.45-0.75		
Steel (Mild)	Steel (Mild)	0.74	0.57		0.09-0.19
Steel (Hard)	Steel (Hard)	0.78	0.42	0.05 -0.11	0.029-0.12

http://engineershandbook.com/Tables/frictioncoefficients.htm

Functional Aspects Requirements of the Well.

However to understand the potential effects we need to understand what is actually happening in a well when we are running these items in.

A well is built up of one or more different sections.

1. Always an initial Vertical section lined with steel pipe.
2. Then either a vertical section of Open hole Well section or a
3. Horizontal section lined with steel or as is more common now a
4. Horizontal Open Hole Well section.

It is worth remembering when in a vertical section that contact with the steel tends not to be too heavy or large because little equipment weight is involved. It is only when you get into the more horizontal section (note it is not perfectly horizontal and could be anywhere up to an angle of 30-45 from the horizontal.)

In the initial section little to know wear is experienced, however when wear can be seen this is often in new wells and is the result of pipe dope mixed with sand/debris from incorrect/over doping of connections combined with poor clean outs/mill scale from pipes.

In the second situation the effects of wear are also quiet small for the simple reasons running in is slow and contact with the rock surfaces is limited and small. However a new factor can now play a role. The initial running guide size remains constant when going into the well with the exception of the effects of thermal expansion on the metals. The swelling rubber however undergoes thermal expansion and here the expansion coefficient is many factors greater than that of steel. Added to this is the fact that the elastomer is swelling while going into the well adding more to the diameter with time. The combination of swell and thermal expansion means that in the lower half of the well the Running guides are only really effectively functioning as guides rather than as protectors from wear to the elastomers. This is also so for the horizontal section whether steel clad or open hole. However because of the thermal expansion its ability to grip to the OCTG is potentially affected. As a mitigating situation is the fact that in most horizontal applications the use of friction reducer lubricants is now a more common

Locking Of Rings

In all of the above we have looked in depth at The various aspects of Locking Ring/Running guides from a mechanical properties aspect and a functional aspect. However an integral part of the locking rings are the grub screws used to lock the ring to the pipe. In a previous report we have looked at the ability to lock the rings into place on the OCTG. The tests conducted gave the following summary results.

Test Nr	Grub Screw Angled	Grub Screw at Right Angles	Loctite 3425 A+B	Otto Coll Rapid	Bonded Rubber Guides	Ring OD 5,5 inch ft/lbs	Pipe OD 4,5 Inch ft/lbs	Performance Percentage
1	**YES**					4023	4917	125%
2		**YES**				3216	3931	100%
3	**YES**		**YES**			5944	7265	185%
R-3	**YES**		**YES**			7820	9558	243%
4	**YES**			**YES**		5115	6252	159%
5			YES			5690	6954	177%
6				YES		4208	5143	131%
7					YES	5072	6200	158%
R-2		**YES**				4017	4910	125%
R-5			**YES**			7460	9118	232%

Test Nr.	Program Tube Diameter	Final Torque ft/lbs	Unit OD 5,5 inch ft/lbs	Pipe OD 4.5 inch ft/lbs
1	9,625	2299	4023	4917
2	4,500	3931	3216	3931
3	4,500	7265	5944	7265
3a	5,000	8602	7820	9558
4	5,000	5627	5115	6252
5	5,000	6258	5690	6954
6	5,000	4629	4208	5143
7	***5,000***	***5580***	***5072***	***6200***
8 (R2)	9,625	2295	4017	4910

9 (R5)	5,000	8206	7460	9118

Test Nr	Comments
1	Test with Standard Oblique running guide angled grub screws
2	Test with Industry Standard Perpendicular grub screws
3	Test with Angled grubs screws with Loctite between Pipe Body and Grub Screw body
3a	Repeat of Test 3 due to maximum torque value of bucking unit. (Test value max slipping)
4	Angled Grub screws with Otto Epoxy instead of Loctite
5	Without Grub screws but with only Loctite Epoxy Locking method (Test value max slipping)
6	Test without Grub screws but with only Otto Epoxy as Locking method
7	Bonded Elastomer instead of Steel Body and Loctite (Test value max slipping)
	Test on Short Pipe 2 meter configuration
8 (R-2)	Repeat of Test 2 due to confirmation of value on another Diameter Bucking program
9 (R-5)	Repeat of Test 5 due to Testing with Sleeve not chemically cleaned

In the above data it can be seen that whilst the figures look impressive that test 7 (Bonded elastomer) gives the simplest and one of the best results as it has not reached a maximum due to this value exceeding the power-tong gripping force.

The grub screws have two functions, namely to hold the running guide lock ring in place while running into the well and a secondary function regarding swelling rubber restraint while this is in the well. In none of these functional applications does it contribute directly to pressure containment.

3.0 Conclusions

A number of conclusions can be drawn from all of the above:

- Metallurgy choice of the Ring/guide is an important part of its continuing to function at elevated temperature.
- Metallurgy Type and shape of Grub screws is important
- Wear resistance is not a functional choice for metal running guides, elastomers function just as well and for exotic metallurgies are Functionally as good for far less cost.
- Bonded Elastomer rings can offer all the function that a metal ring alludes to.

4.0 Recommendations

- For Steam applications where bonding of guides is not an option and metallurgy can be a problem due to thermal expansion etc an alternative cost effective long term solution needs to be found if the customer requires it.
- For Normal temperature applications (+/- 160 C) a Bonded Running Guide is a more effective solution to grub screw locking metal guides and should be the de facto standard.
- For Corrosion resistant applications metal guides should not be considered as an option

5.0 References

ISO 4649 - Rubber, vulcanized or thermoplastic Determination of abrasion resistance using a rotating cylindrical drum device.

All Coefficients:

http://www.engineeringtoolbox.com/linear-expansion-coefficients-d_95.html

http://www.engineershandbook.com/Tables/frictioncoefficients.htm

6.0 Authorisation

Author	Signature	Date
Approved Technical	Signature	Date
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Manufacture Contact Information

Ruma Products B.V.
Zeppelinstraat 5
7903 BR Hoogeveen
The Netherlands

Tel. +31 (0) 528 260 160

Manufacture Stamp and Signature