Evaluating Factors Affecting O-ring Insertion Force Using General Factorial Design

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Abstract

In this work, a general factorial design was used to evaluate the roles of lubricant type, insertion speed, bore size and operator technique in radial O-ring insertion. It was found that the type of lubricant had the most significant influence on the insertion force reading. By using the right type of lubricant, such as P-80® Emulsion Temporary Rubber Lubricant, Rubber Slide® Assembly Lubricant or Water Activated Dry Film Lubricant**, the insertion force readings decreased tremendously. The insertion speed and bore size as well as the interactions between some factors (lubricant type and insertion speed; lubricant type and bore size) also showed significant influences on the final friction reading, but their influences were much less than the type of lubricants reflected by the F values and *p*-values (F value for lubricant type factor: 1151.31 with *p*-value <0.0001; F value for bore size: 94.53 with *p*-value < 0.0001; F value for assembly speed: 24.51 with *p*-value < 0.0001; F value for interaction of lubricant type and bore size: 16.98 with *p*-value < 0.0001F; value for interaction of lubricant type and insertion speed: 2.49 with *p*-value of 0.0170). Operators did not have significant influence on the insertion force readings. This information is useful to help engineers select the right conditions for easy radial O-ring insertion.

Introduction

O-rings can be made of various materials, but the most common type is elastomeric[1]. Elastomeric O-rings can be used as seals in sealing joints. A sealing joint consists of a shaft and O-ring assembly in which the sealing joint is inserted into a bore[2]. During the insertion process, the O-ring is compressed, resulting in a high insertion force. In order to assemble the seal properly, an operator needs to continuously push the bore onto the piston. Consequently, too high of an insertion force can damage the elastomeric O-rings, resulting in a shorter shelf life or even leakage.

Factors affecting the insertion force include O-ring material type, O-ring lubrication, bore size, insertion speed, operators, etc. There are various lubricant chemistries available to aid elastomeric part assembly. Water-based lubricants have certain advantages over those that are solvent-based because the solvents may cause compatibility issues with the assembled elastomeric parts. Another disadvantage to using solvent-based lubricants is the environmental concerns associated with them. A Water Activated Dry Film Lubricant formula is currently being developed, which is intended to be precoated onto elastomeric parts such as O-rings. When the part needs to be assembled, the precoated elastomer can be dipped into water. Water activates the lubricating effect of the coating and lowers the assembly friction.

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**This formula is under development and it will be finalized soon; the final trade name to be determined.

In this study, four factors were evaluated for their influence on the insertion force *via* a general factorial design. The factors evaluated were lubricant type, insertion speed, bore size and operators. The results can be used as a reference for design engineers and operators to select the optimal conditions for a seal joint insertion operation.

Experimental

1. Materials and Apparatus
   a. O-rings: E0603 2-121 and E0603 2-125 (EPDM, Parker Hannifin Corporation);
   b. P-80® Emulsion Temporary Rubber Lubricant (International Product Corporation; Denoted as P-80® Emulsion below);
   c. Rubber Slide® Assembly Lubricant (International Product Corporation);
   d. Water Activated Dry Film Lubricant (International Product Corporation);
   e. PTFE pre-lube spray;
   f. Molybdenum disulfide powder;
   g. Graphite dry film lube;
   h. Bores and pistons to simulate an O-ring sealing joint (bore sizes: 31.72 and 38.07 mm);
   i. Mecmesin AFG 1000N force gauge;
   j. Mecmesin MultiTest-*d* Digital Motorized Test Stand;
2. O-ring preparation for testing

   The molybdenum disulfide powder was suspended in tap water at 5% (w %). All the other lubricants were used as is. The O-rings were pre-coated with PTFE pre-lube, 5% molybdenum disulfide and the Water Activated Dry Film Lubricant, respectively. The pre-coated O-rings were allowed to dry at room temperature for a week. For the insertion force testing, the dry films of PTFE pre-lube and 5% Molybdenum disulfide were tested as is while the O-rings with the Water Activated Dry Film Lubricant were dipped briefly into tap water to activate the lubrication effect. The P-80® Emulsion and Rubber Slide® Assembly Lubricant were used as typical line lubricants; they were applied to the O-rings followed immediately by assembly.
3. Insertion force testing procedure

   The set-up for insertion force testing is shown in Figure 1.

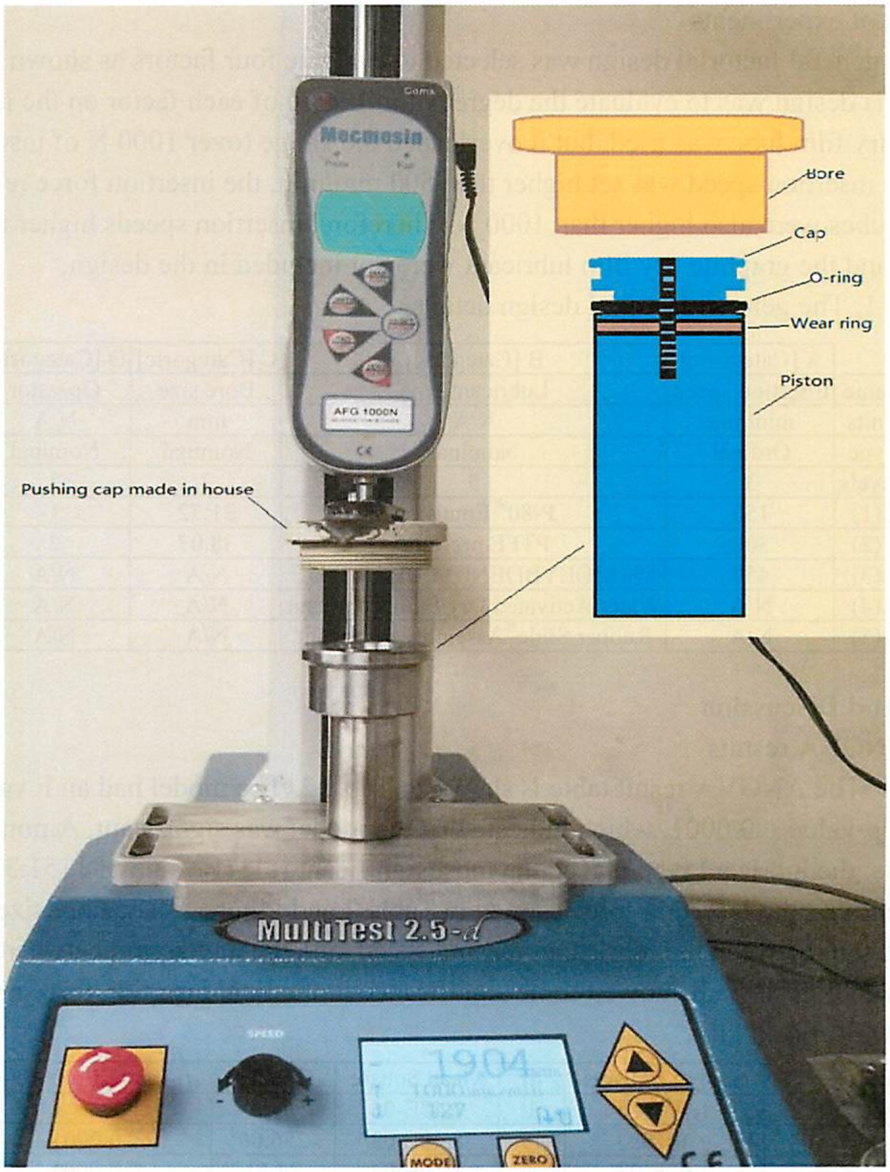

Figure 1. The set-up for insertion force testing.

The testing procedure is as follows.

a. Screw the piston on the platform of the stand.
b. Place an O-ring with respective lubricant on the piston.
c. Screw the cap on top of the piston.
d. Place the bore loosely on top of the piston with the cap on.
e. Set up the force gauge meter and zero it.
f. Select the right insertion speed and the stop position of the stand.
g. Push the start button to push down the bore and let it pass over the O-ring.
h. Record the maximum force reading of the gauge, which is the insertion force of each trial.

3. Design of experiments

A general factorial design was selected to evaluate four factors as shown in Table 1. The goal of this design was to evaluate the degree of influence of each factor on the insertion force. A graphite dry film lube was tried, but it overloaded the gauge (over 1000 N of insertion force). When the insertion speed was set higher than 500 mm/min, the insertion force readings for some dry film lubes were also higher than 1000 N. Therefore, insertion speeds higher than 500 mm/min and the graphite dry film lubricant were not included in the design.

Table 1. The general factorial design details

	A [Categoric]	B [Categoric]	C [Categoric]	D [Categoric]
Name	Insertion speed	Lubricant type	Bore size	Operator
Units	mm/min	N/A	mm	N/A
Type	Ordinal	Nominal	Nominal	Nominal
Levels	3	5	2	2
L(1)	150	P-80® Emulsion	31.72	1
L(2)	300	PTFE pre-lube	38.07	2
L(3)	450	5% MOLYBDENUM DISULFIDE	N/A	N/A
L(4)	N/A	Water Activated Dry Film Lubricant	N/A	N/A
L(5)	N/A	Rubber Slide®Assembly Lubricant	N/A	N/A

Results and Discussion

1. ANOVA results

The ANOVA result table is shown In Table 2. The model had an F value of 256.66 and a *p*-value < 0.0001, which indicate that the model was significant. Among all of the factors, the lubricant type played the most significant role (F value of 1151.31) in determining the insertion force as seen in Table 2 and Figure 2. The bore size, insertion speed, interaction between the lubricant type and speed, and the interaction between the lubricant type and bore size all showed some significance in the final insertion force readings.

Table 2. ANOVA result table

Source	Sum of Squares	df	Mean Square	F Value	*p*-value (Prob > F)	
Block	1.47E-06	1	1.47E-06			
Model	0.16	19	8.48E-03	256.66	< 0.0001	significant
A-Insertion speed	1.62E-03	2	8.10E-04	24.51	< 0.0001	
B-Lubricant type	0.15	4	0.038	1151.31	< 0.0001	
C-Bore size	3.12E-03	1	3.12E-03	94.53	< 0.0001	
AB	6.57E-04	8	8.21E-05	2.49	0.0170	
BC	2.24E-03	4	5.61E-04	16.98	< 0.0001	
Residual	3.20E-03	97	3.30E-05			
Cor Total	0.16	117				

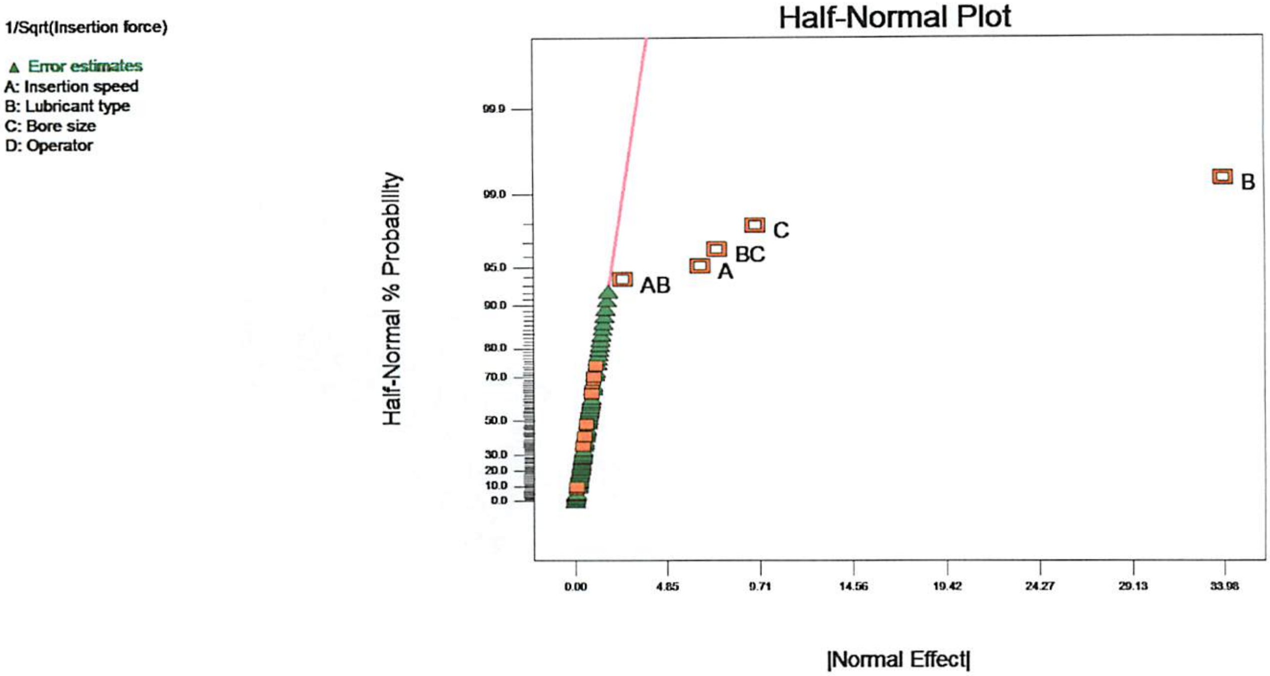

Figure 2. Half-Normal Plot of the effects of selected factors.

In Table 3, the second part of the ANOVA results is displayed. The Adj R-Squared and the Pred R-Squared values were very close to each other with a difference much smaller than 0.2 between these two values. The Adeq Precision was also much higher than the desired value of 4 for the signals to be adequate, indicating good testing precision.

Table 3. ANOVA result part 2.

Std. Dev.	5.75E-03	R-Squared	0.9805
Mean	0.098	Adj R-Squared	0.9767
C.V. %	5.87	Pred R-Squared	0.9712
PRESS	4.74E-03	Adeq Precision	42.839

The significance of each factor can be seen in Figure 3. In Figure 3(A), the interaction of lubricant type and insertion speed is illustrated. It can be seen that the lubricant type played the major role in determining the insertion force at whichever insertion speed. Similarly in Figure 3(B), the main effect was still the lubricant type.

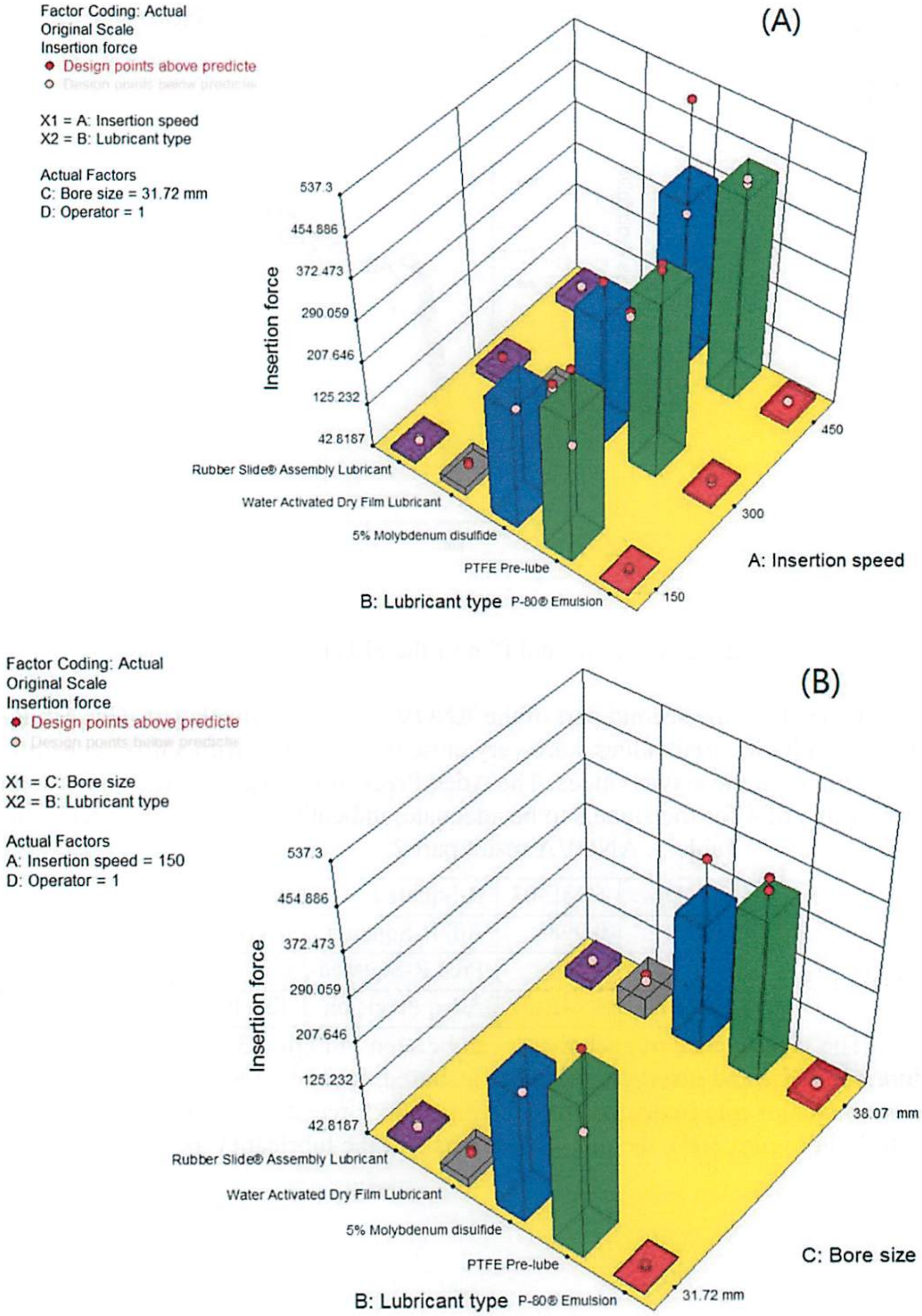

Figure 3. Illustration of interactions. (A) Lubricant type and insertion speed; (B) Lubricant type and bore size.

2. Solutions for low insertion force

In order to increase O-ring shelf life and avoid O-ring damage, minimal insertion force is desired. In the optimization process, all four factors (lubricant type, bore size, insertion speed and operator) were kept in range while insertion force was set to be minimized to search for the best O-ring insertion conditions. It can be seen from the solution table below that all three lubricants manufactured at International Products Corporation can render low insertion forces; none of the first 36 solutions contains the other dry film types.

Table 4. Solutions obtained in the optimization process

Number	Insertion speed	Lubricant type	Bore size	Operator*	Predicted insertion force	Desirability
1	150	P-80® Emulsion	31.72 mm	2	44.7	0.963
2	150	P-80® Emulsion	31.72 mm	1	44.7	0.963
3	150	Rubber Slide® Assembly Lubricant	31.72 mm	2	49.9	0.873
4	150	Rubber Slide® Assembly Lubricant	31.72 mm	1	49.9	0.873
5	300	P-80® Emulsion	31.72 mm	2	49.9	0.872
6	300	P-80® Emulsion	31.72 mm	1	49.9	0.872
7	450	P-80® Emulsion	31.72 mm	2	54.1	0.799
8	450	P-80® Emulsion	31.72 mm	1	54.1	0.799
9	150	P-80® Emulsion	38.07 mm	1	57.1	0.748
10	150	P-80® Emulsion	38.07 mm	2	57.1	0.748
11	150	Water Activated Dry Film Lubricant	31.72 mm	2	58.6	0.722
12	150	Water Activated Dry Film Lubricant	31.72 mm	1	58.6	0.722
13	450	Water Activated Dry Film Lubricant	31.72 mm	1	59.5	0.705
14	450	Water Activated Dry Film Lubricant	31.72 mm	2	59.5	0.705
15	300	Water Activated Dry Film Lubricant	31.72 mm	1	59.7	0.702
16	300	Water Activated Dry Film Lubricant	31.72 mm	2	59.7	0.702
17	300	Rubber Slide® Assembly Lubricant	31.72 mm	1	60.0	0.698
18	300	Rubber Slide® Assembly Lubricant	31.72 mm	2	60.0	0.698
19	150	Rubber Slide® Assembly Lubricant	38.07 mm	2	60.1	0.695
20	150	Rubber Slide® Assembly Lubricant	38.07 mm	1	60.1	0.695
21	450	Rubber Slide® Assembly Lubricant	31.72 mm	2	62.8	0.648
22	450	Rubber Slide® Assembly Lubricant	31.72 mm	1	62.8	0.648
23	300	P-80® Emulsion	38.07 mm	2	64.6	0.616
24	300	P-80® Emulsion	38.07 mm	1	64.6	0.616
25	450	P-80® Emulsion	38.07 mm	1	70.9	0.507
26	450	P-80® Emulsion	38.07 mm	2	70.9	0.507
27	300	Rubber Slide® Assembly Lubricant	38.07 mm	2	73.7	0.459
28	300	Rubber Slide® Assembly Lubricant	38.07 mm	1	73.7	0.459
29	450	Rubber Slide® Assembly Lubricant	38.07 mm	1	77.5	0.391
30	450	Rubber Slide® Assembly Lubricant	38.07 mm	2	77.5	0.391
31	150	Water Activated Dry Film Lubricant	38.07 mm	1	83.1	0.294
32	150	Water Activated Dry Film Lubricant	38.07 mm	2	83.1	0.294
33	450	Water Activated Dry Film Lubricant	38.07 mm	1	84.7	0.267
34	450	Water Activated Dry Film Lubricant	38.07 mm	2	84.7	0.267
35	300	Water Activated Dry Film Lubricant	38.07 mm	1	85.0	0.261
36	300	Water Activated Dry Film Lubricant	38.07 mm	2	85.0	0.261

Conclusions

By using a general factorial design, four factors (lubricant type, bore size, insertion speed and operator) were evaluated for their roles in affecting insertion force of O-rings to simulate an O-ring sealing joint. Among all the factors, the lubricant type plays the most significant role in determining the insertion force. Dry film lubricants such as PTFE, molybdenum sulfide and graphite types are convenient to use for the end users, but they don't perform well in this application. All three International Products Corporation water-based products (P-80® Emulsion, Rubber Slide® Assembly Lubricant and Water Activated Dry Film Lubricant) could lower the insertion force tremendously. The Water Activated Dry Film Lubricant in particular may benefit O-ring end users because O-rings can be precoated. This study can be used as a reference for technical personnel who deal with O-ring sealing joints assembly and others who are searching for better ways to lower friction for elastomeric part assembly.

References

1. Corporation, P.H., *Parker O-Ring Handbook.* 2007.
2. Samuel J. Tomlinson, et al., *Radial O-Ring Insertion Force Optimization for Functionality and Assembly.* SAE International, 2017(2017-01-0326).