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STICK SLIP EVALUATION

Self-lubricated Bearing Material Assessment

DATE: 18November2015

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Background

Thordon Bearings Inc. manufactures self-lubricated bearing materials for a wide range of applications in Marine, Hydroelectric, and Industrial markets. In applications such as sliding wear pads for water control gates or guide rails, the friction characteristics of the bearing material will have a significant impact on the smooth and reliable performance of the gate. Stick-slip behavior is characterized by the spontaneous jerking motion that can occur while two objects are sliding over each other. In the case of a hydraulic or mechanically driven mechanism, excessive stick slip results in higher than expected loads and forces on the equipment that is creating the motion.

In order to understand and characterize the influence of bearing material selection as well as roughness and material used for the counter face, Thordon Bearings has engaged a 3rd party engineering firm (RD Energie) to carry out a test of this behavior comparing several different material combinations. Sliding speeds and test pressures were selected that are believed to be typical in the design of this type of sliding pad mechanism. The method, result and conclusion of this testing program is presented in the following report.

Thordon Bearings Comment Regarding Material Selection

Based on the testing presented in the attached report, ThorPlas (White or Blue) can be considered as suitable materials for sliding wear pad applications and would be expected to exhibit less stick-slip behavior than the Orkot TXM phenolic resin material at the speeds and loads tested.

When compared with the UHMWPE bearing material, ThorPlas will provide similar low friction characteristics, but in abrasive wear testing done previously ThorPlas has been shown to provide better resistance to wear and therefore is expected to provide longer bearing life than UHMWPE strips.

ThorPlas is a self-lubricated thermoplastic material and can be used in low speed sliding or rotating applications at bearing pressures up to 45MPa in wet or dry applications, without any additional lubrication required. More information can be found at www.thordonbearings.com.

Project No: 150818-RMH

Stick-Slip testing

Materials assessment

October 2015

Prepared by: _______________ November 10, 2015
Michael Beaudoin, Ing. — Date

Verified by: _______________ Novembre 10, 2015
Simon Rousseau, Ing. — Date

Rev.	Date	Description	Seal
0	2015-11-10	For comments	INGÉNIEUR - ENGINEER Michaël Beaudoin 5037996 QUÉBEC 2015-11-10

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1 Introduction

In the industrial field, wear components (occasionally called wear pads) are used to allow pieces to move easily on others. Those low friction components can be manufactured from few materials available in the field such as bronze, plastics, composites, etc. In addition to prevent premature wear, they allow to reduce the equipment's power needed to move loads.

However, in some low speed systems, a beating or oscillating phenomenon can be observed during the use of those products. This phenomenon, called "Stick-Slip motion" or "Stick-Slip", occurred when the elasticity of the system (cables, flexion of beams, springs, etc.) allow to the load to stick to its sliding face. At this point, when the load is stationary, it is the static friction coefficient which governs the link between the load and the sliding face. This one, higher than the dynamic coefficient, retains the load and ensures that the system stretches until the force of this "spring" is sufficient to overcome the static friction force. The load then starts moving and the friction decreases to the dynamic friction. As the force accumulated in the «spring» is now higher than the needed force to keep the load moving, the load accelerates and overtakes the motor, thereby retracting the "spring". Once the "spring" no longer imposes sufficient force on the load, the load stops again. This cycle is repeated again and again throughout all the duration of the operation, creating the Stick-Slip.

However, the presence and the intensity of this phenomenon are highly influenced by a lot of external factors. The difference between static and dynamic friction coefficients, the properties of sliding surfaces, the contact pressure between surfaces, the speed itself, the surfaces contamination and the overall elasticity of the systems are few ones. Those factors make this Stick-Slip phenomenon an extremely hard to quantify phenomenon. It is therefore almost impossible to determine under what conditions of use it will be present and in what order of intensity it will act.

That's why manufacturers of wear materials are generally not apt to provide the necessary information to predict the behavior that each of their products will have in specific conditions. A bench test, visible on Figure 1, was achieved to analyse the behavior of those materials in various conditions.

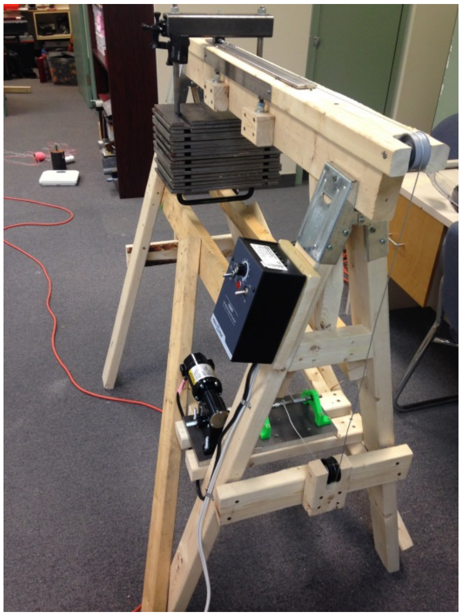


Figure 1 : Stick-Slip phenomenon's bench test

2 Testing

Following discussions with RMH, five materials and three conditions of use were found interesting to be tested to valid the presence of Stick-slip phenomenon.

Materials to be tested are following:

- Orkot TXMM
- UHMWPE
- Thordon HPSXL
- ThorPlas White
- ThorPlas Blue

Conditions of use are following:

- Translation speed :
  - 1,5 mm/s
  - 3 mm/s
- Contact pressure between sample and sliding face:
  - 200 PSI
  - 400 PSI
- Material and surface finish of sliding face :
  - 304L Stainless steel with raw surface finish
  - 304L Stainless steel with polished surface finish
  - UHMWPE with raw surface finish

3 Table of Results

Here are the results obtained during tests on Stick-Slip. The number inside each square is the number assigned to different tests according to chronological order of testing. For each test, a video is available and has the same number.

Table 1 : Results of Stick-Slip testing

Legend:

Without Stick-Slip
Intermittent Stick-Slip
Constant Stick-Slip
Constant and intense Stick-Slip

		304L SS, Raw		304L SS, Polished		UHMWPE	
		1,5 mm/s	3 mm/s	1,5 mm/s	3 mm/s	1,5 mm/s	3 mm/s
Orkot TXMM	400 PSI	#7	#8	#9	#10	#11	#12
	200 PSI	#1	#2	#3	#4	#5	#6
UHMWPE	400 PSI	#13	#14	#15	#16	#17**	#18**
	200 PSI	#19	#20	#21	#22	#23**	#24**
Thordon HPSXL	400 PSI	#25	#26	#27	#28	#29	#30
	200 PSI	#31	#32	#33	#34	#35	#36
ThorPlas White	400 PSI	#37	#38	#39	#40	#41	#42
	200 PSI	#43	#44	#45	#46	#47	#48
ThorPlas Blue	400 PSI	#49	#50	#51	#52	#53	#54
	200 PSI	#55	#56	#57	#58	#59	#60

(**) Despite the fact that the tests #17-#18 and #23-#24 didn't show any Stick-Slip, it's important to mention that the friction coefficients of those tests seemed to be higher than the majority of other cases. The purpose of this report and those tests are not covering the friction coefficients in detail, so no analyse or measurement of them has been done with precision. Nevertheless, some observations made during the tests allow affirming it without any problem. Firstly, the samples translation speed was slower even if the motor settings were the same. Secondly, the sliding face was moving on the support easily than the sample was moving on the sliding face. This makes undulating the UHMWPE flat bar.

A study covering the friction coefficients' evaluation of each condition could be interesting to complete the overall picture of those materials.

4 Results analysis

The above table allows us to do several observations for each different condition that occurred during the testing. The following paragraphs resume each of these conditions by elaborating on their importance and influence on the Stick-Slip phenomenon.

4.1 Surface finish of sliding face

The surface finish of the sliding face is undoubtedly the condition among those studied which influences the more drastically the phenomenon. We can clearly see that any Stick-Slip has been present during all tests made on the UHMWPE and 304L SS Polished sliding faces, and that regardless of the other conditions. It should be noted that the material of the sliding face itself doesn't affect the phenomenon as much as the surface finish type. It is possible to see that for a same material, the 304L stainless steel, we obtain different results depending on whether it is raw or polished. See in Appendix A the pictures of tools used to polish the stainless steel flat bar.

4.2 Translation speed of sample

By observing the data of the table, we can notice that the sample translation speed influences the beating intensity. During all tests made on the 304L SS Raw sliding face, the Stick-Slip intensity decreases with the increasing of speed. In few cases (tests #1-#2 and tests #55-#56), this increasing even stops completely the phenomenon. It is likely that for all conditions still showing Stick-Slip at speed of 3 mm/s, it would be possible to make it disappear by further increasing translation speed. However, it is not possible to predict theoretically the exact speed at which the phenomenon would cease to be present. Nevertheless, other tests can be performed to verify the limits of this Stick-Slip.

4.3 Contact pressure between sample and sliding face

Once again, we can see that the magnitude of the phenomenon varies with the condition of contact pressure between samples and sliding faces. However, this time, it's impossible to tell whether the increasing of contact pressure increases of decreases the Stick-Slip intensity, or vice versa. Indeed, in the case of ThorPlas Blue, an increasing of the pressure (tests #55-#49) decreases the phenomenon while in the cases of Thordon HPSXL (tests #31-#25) and ORKOT TXMM (tests #2-#8), an increasing of the pressure increases the phenomenon.

4.4 Material of sample

The material type itself used for the samples influences significantly the phenomenon. The results show that some of them seem to offer a better behavior than the others during low-speed displacements on different studied surfaces. For instance, it's possible to notice that UHMWPE and ThorPlas White samples didn't show any Stick-Slip during all their tests. Another material that stood out is the ThorPlas Blue, for which only a soft intermittent beating has been noticeable on one test (Test #55). For their part, the Orkot TXMM and the Thordon HPSXL haven't done well in several testing. Both materials have moved with intense jerky movements on the raw stainless steel sliding face. The intensity of the Stick-Slip varied in function of the speed and the contact pressure of different tests but remained generally strong.

5 Conclusions and important details

At the light of those tests, several observations were issued during results analysis. Among other things, the fact that the main conditions that influence the Stick-Slip phenomenon are the surface finish of the sliding face and the choice of the wear components material.

It is therefore possible to affirm that a 304L SS polished and a UHMWPE sliding face are less suitable to Stick-Slip than a 304L SS raw sliding face. It is also possible to tell that the UHMWPE and the ThorPlas White showed better behaviors against the Stick-Slip than other materials in the tests conditions.

IMPORTANT!

Results analysis: It is important to mention that the characteristics and the results mentioned above are valid only for the tested and analyzed conditions with the bench test. It is not possible to extrapolate to predict behaviors using other conditions and other circumstances. We cannot say with certainty, for example, that because the polished stainless steel sliding face eliminated the phenomenon with all tested samples that it will be the same with all other existing materials.

It is also important to understand that the obtained results and conclusions are from tests performed once for each condition with unique samples and sliding surfaces.

Manufacturing batch: Each of these components has their own characteristics from their manufacture. For example, the chemical composition of the same material may vary from one production to another and thereby change the properties related to Stick-Slip. In the same way, the grain direction of steel, the origin of the sliding face (plate, flat bar, different manufacturers, etc.) can change the surface characteristics for a same material with the same finish.

In other words, it's not because a sample shows a good result on a raw stainless steel flat bar, or conversely, a bad result, that it will show the same result on another raw flat bar bought at another moment from another manufacturer.

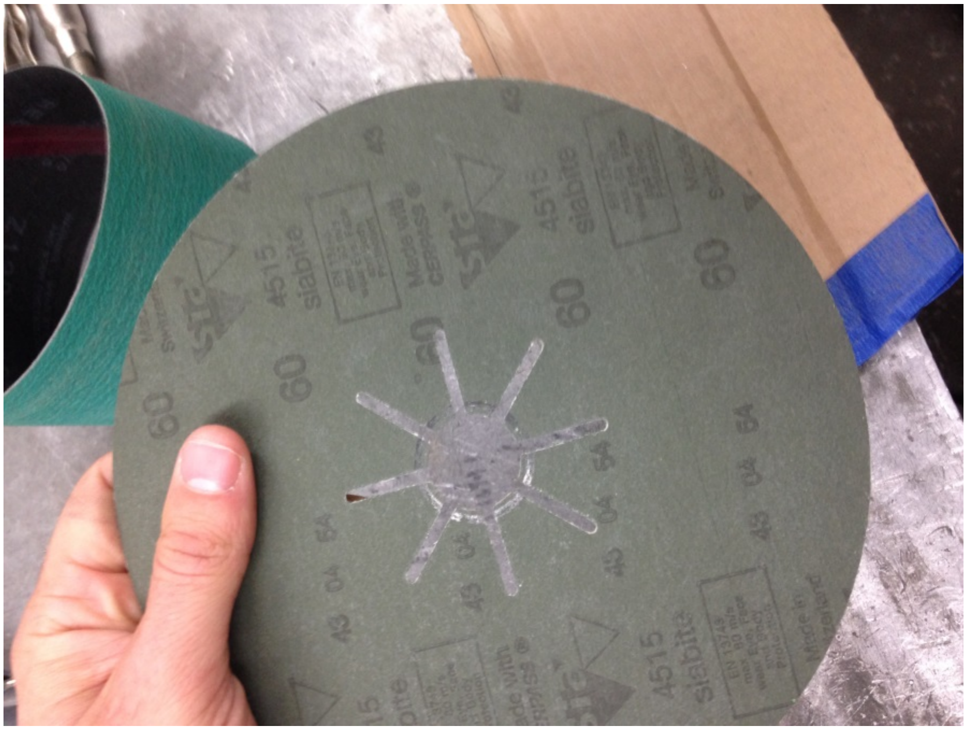
Time effect: In addition, an uncertainty with the behaviors consistency in the time remains since only new components were used during tests. With the time, wear components lose of their thickness. This can change their characteristics related to Stick-Slip, particularly for non-homogeneous material (as materials made of layers). The wear of sliding pads can also coats the sliding faces with lubricating products (from the pads themselves) and alters the behavior. The finish of sliding faces (and their properties) can also be modified by the repeated passages of mobile charges that can act as "fine sand papers".

Design: Of course, those tests allow a better understanding of the phenomenon and thus allow us to better direct our choice of materials and external conditions during a new design. However, once all conditions of a project are established, a series of additional tests must be carried out to verify the repeatability of the results in those conditions. Some tests must also be carried out to validate the behavior over time.

Finally, do not forget to validate the usual mechanical properties of material resistance (compressive strength, etc.) for the pads and that friction coefficients correspond to the project needs.

Appendix A

Pictures of polishing tools


4515
siabite
60


BOC
Industriel


Z120
Z120
WY5
WARNING


X P220
X P220
P220
KLINGSPOR

Project no: 150818-RMH

Evaluation of friction coefficients

May 2016

Prepared by: ______________________ MAY 19, 2016

Michael Beaudoin, P. Eng. Date

Verified by: ______________________ may 19, 2016

Simon Rousseau, P. Eng. Date

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1 Introduction

Following the report «Stick-Slip testing, Materials assessment, October 2015», RMH Industries commissioned RD Énergie to conduct an additional study. The purpose of this study was to evaluate the static and dynamic friction coefficients of some materials under certain conditions presented in the October 2015 report.

2 Testing

RMH has established a list of materials and conditions that must be tested.

Materials:

- Orkot TXMM
- UHMWPE
- ThorPlas Blue

Conditions:

- Translational speed :
    - 1,5 mm/s
    - 3 mm/s
- Contact pressure between sample and sliding face:
    - 200 PSI
    - 400 PSI
- Material and surface finish of sliding surface :
    - 304L Stainless steel with polished surface finish
    - UHMWPE
    - 304L Stainless steel with raw surface finish

For information, all of these combinations have been tested in dry conditions. It must be considered that the samples and the sliding surfaces used for this study are the same as those used for the previously mentioned report. Pictures of the tools used to polish the 304L stainless steel are provided in Appendix A of the report «Stick-Slip testing, Materials assessment, October 2015».

3 Tables of Results

The following tables show the magnitude of the static and dynamic friction coefficients obtained from the tests.

Tableau 1 : Friction coefficients on polished stainless steel 304L sliding surface

		Stainless steel 304L, Polished		
		µ static	µ dynamic	
			1,5 mm/s	3 mm/s
Orkot TXMM	400 PSI	0,13	0,14 - 0,14	0,16 - 0,16
	200 PSI	0,10	0,12 - 0,12	0,13 - 0,14
UHMWPE	400 PSI	0,09	0,08 - 0,08	0,09 - 0,10
	200 PSI	0,07	0,08 - 0,08	0,08 - 0,10
ThorPlas Blue	400 PSI	0,09	0,10 - 0,11	0,09 - 0,12
	200 PSI	0,10	0,11 - 0,11	0,09 - 0,12

Tableau 2 : Friction coefficients on UHMWPE sliding surface

		UHMWPE		
		µ static	µ dynamic	
			1,5 mm/s	3 mm/s
UHMWPE	400 PSI	0,48	0,43 - 0,48	0,44 - 0,46
	200 PSI	0,37	0,35 - 0,41	0,42 - 0,44
ThorPlas Blue	400 PSI	0,10	0,07 - 0,07	0,07 - 0,07
	200 PSI	0,11	0,07 - 0,07	0,07 - 0,07

Tableau 3 : Friction coefficients on raw stainless steel 304L sliding surface

		Stainless steel 304L, Raw		
		µ static	µ dynamic	
			1,5 mm/s	3 mm/s
ThorPlas Blue	400 PSI	0,17	0,12 - 0,13	0,12 - 0,14
	200 PSI	0,15	0,11 - 0,13	0,12 - 0,13

4 Results Analysis

Here are some observations made during the analysis of the results.

- It is possible to notice that the ThorPlas Blue sliding on UHMWPE and on raw stainless steel 304L behaves according to the theoretical model. In other words, the static friction coefficient is higher than the dynamic friction coefficient. Furthermore, the dynamic friction coefficient stays relatively constant despite changes in translational velocity.

- Tests performed with the UHMWPE sliding on UHMWPE confirm the comment « (**) » in section 3 «Table of Results» of the report « Stick-Slip testing, Materials assessment, October 2015» about the tests #17-#18 and #23-#24. The friction coefficients are very high, between 0,37 - 0,48 in static and 0,35 - 0,48 in dynamic.

- The results show unusual behavior of static and dynamic coefficients of friction. Usually the static friction coefficients are higher than dynamic. However, the tests made on the polished stainless steel 304L show slightly higher dynamic friction coefficients, or at least very similar to those static. The dynamic friction coefficients appear to be rising with the speed of translation. The dynamic friction coefficients of ThorPlas Blue seem to be a bit variable at 3mm/s but they remain, on average, still higher than the static coefficients.

  It is possible that this inversion of static and dynamic coefficients of friction partly explains why all the tests done on the polished stainless steel 304L sliding surface in the report «Stick-Slip testing, Materials assessment, October 2015» presents no stick-slip. If we consider that the static coefficient of a polished stainless steel 304L flat bar would be lower than the dynamic coefficient, the phenomenon of the "spring which stretches and retracts" (explained in the section 1 of the above mentioned report) will not happen. The dynamic friction coefficient, now larger than the static friction coefficient, prevents the mass to accelerate too quickly and catch up the motor. The mass then moves with continuous motion without stick-slip.

IMPORTANT!

Note that the details mentioned in section 5 «Conclusions and important details» in the report «Stick-Slip testing, Materials assessment, October 2015» are still valid and applicable for testing and results presented in this report.