DYNAMIC MODEL OF THE ROLLER FLOAT CONDITION IN ONE-WAY CLUTCH (OWC) APPLIED TO MOTORCYCLE ENGINE STARTERS

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Abstract. *In motorcycle engine starter the rotation of an electric motor (starter motor) is transmitted to the crankshaft to allow engine start up; as the engine starts, the rotation of the crankshaft should not be transmitted to the electric motor armature to avoid system failure due to the high rotational speed of the internal combustion engine. In order to obtain this function the starter system has a one-way clutch (OWC) assembled between the crankshaft and the driven gear that is rotated by the starter motor. The OWC assembly is held in position by the armature shaft of the electric starter motor. Considering the OWC dynamic performance the study of the roller float condition can improve product durability by avoiding excessive contact between roller and race, the components responsible for the torque transmission. Assuming that "roller float" condition happens because the OWC in motorcycle starters is permanently engaged to the engine crankshaft, this can lead to a potential failure mode due to the premature wear of the components in contact, hence this is an important design aspect to be considered during OWC development for motorcycle starters systems. To perform this study a lumped parameter model based on a single roller analysis was developed. The model represents the behavior of the roller when the outer cam is increasing its angular velocity. It comprehends the centrifugal force generated by the rotational speed, the elastic contact that is the focus of the investigation and the roller and cam spring data. All those variables were determined to influence the roller float condition. By changing design variables in the model the angular velocity in which roller float occurs can be modified. Experimental validation has confirmed the simulation results and the potential application of the dynamic model to improve roller clutch performance in the early phases of the Product Development Process.*

Keywords*: dynamic modeling and simulation, lumped parameter modeling, motorcycle starter, one-way clutch (OWC)*

1. INTRODUCTION

In motorcycle engine starter the rotation of an electric motor (starter motor) is transmitted to the crankshaft to allow engine start up. As the engine starts the rotation of the crankshaft should not be transmitted to the electric motor to avoid armature centrifugation and starter system failure due to the high rotational speed of the internal combustion engine.

In order to obtain this function the motorcycle starter system has adopted a One-Way Clutch (OWC) assembled between the crankshaft and the driven gear that is rotated by the electric starter motor, as shown in Fig. 1.

The OWC has the functionality of transmitting the lockup torque in one direction and to free spin in the opposite direction to allow engine start up and protect the electric motor of the starting system.

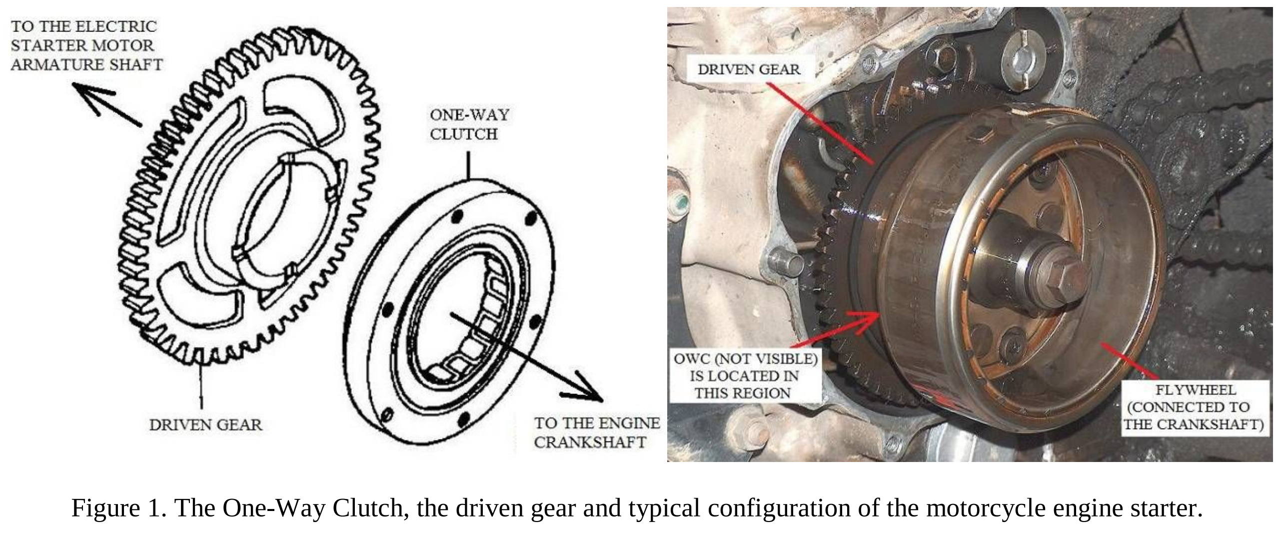


Figure 1. The One-Way Clutch, the driven gear and typical configuration of the motorcycle engine starter.

2. ONE-WAY CLUTCH APPLIED IN MOTORCYCLE ENGINE STARTERS

Different types of OWC are currently under production by motorcycle manufacturers worldwide to be used in electric starter systems. The engineering solutions are slightly different, but enough to influence performance, cost, durability and other critical product specifications when comparing pros and cons of each solution. Here we present a brief description of some of the most common systems. Additional information, if necessary, can be obtained in the respective references at the end of this paper.

2.1. Yamaha concept

Motorcycle manufacturer Yamaha developed and patented a roller OWC that uses rollers positioned by springs against the wedges of the outer race. Figure 2 shows this system that was patented and described in details by Ouchi (1992), as having a caging member (the outer race) that defines a plurality of wedges in which rollers are positioned. Plungers or "spring guides" are located in each bore of the caging member adjacent to each wedge profile as shown in Fig. 2. A coil compressing spring is assembled in each of the bores. The rollers are adapted to cooperate with a cylindrical surface of an inner race fixed for rotation with the gear. As the rollers are, in turn, forced against the cam surfaces by the springs, the rollers are locked with the inner race in one direction. When rotating in the opposite direction the wedge lockup angle allows a wider space to the rollers, enabling them to free spin against the compression spring force only.

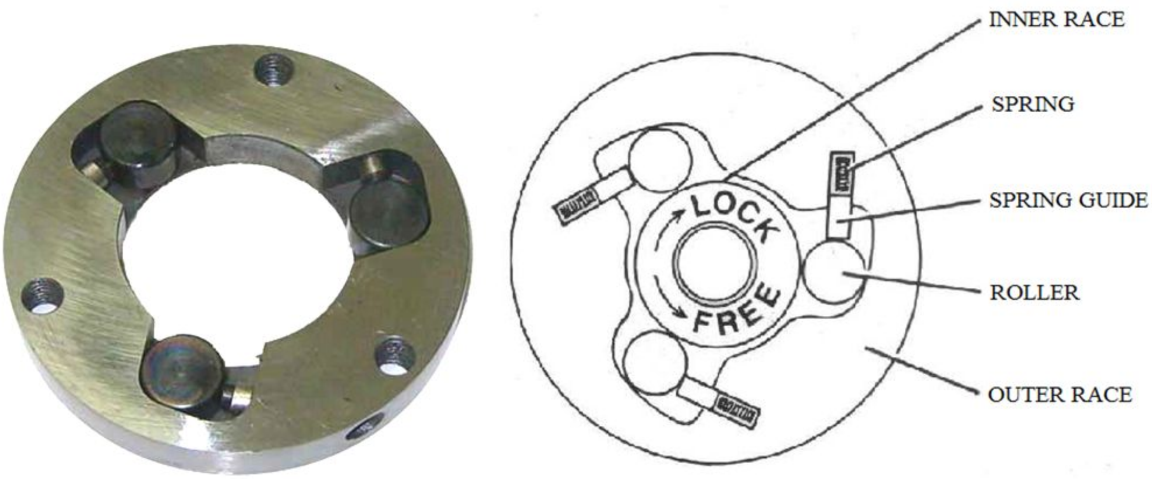


Figure 2. One type of "roller" OWC and its main components (Yamaha, 1992).

This kind of roller OWC was also described in the work done by Chesney and Kremer (1997), where the authors explain the functionalities of the system and discussed the equations that can be used for the proper dimensioning of the clutch given a specific lockup torque. Furthermore, they investigated the dynamic behavior of the OWC when in overrunning mode.

2.2. Honda concept

Another concept was developed and patented by Honda (Akagi and Hosoda, 1991) and was based in a One-Way Clutch having a number of cammed rollers (also called *sprags*) arranged circumferentially between an outer race and an inner race and held between a pair of ring-shaped side plates. The *sprag* OWC is described in the work done by Chesney and Kremer (1998). The authors explain how the lockup and free spin functionalities are obtained from the roller geometry. Also they found that the contact forces in this type of clutch are very high, as seen in the roller OWC. As this is not the main focus of this research further details of the static behavior of the *sprag* OWC can be found in the work done by Chesney and Kremer (1998).

Figure 3 shows the *sprag* OWC design, comprised of cylindrical inner and outer races, multiple *sprags*, cages and energizing spring. Variables OR(i) and OR(o) refers to the outer race inner and outer surfaces, respectively; IR(i) and IR(o) are, consequently, the race inner and outer surfaces.

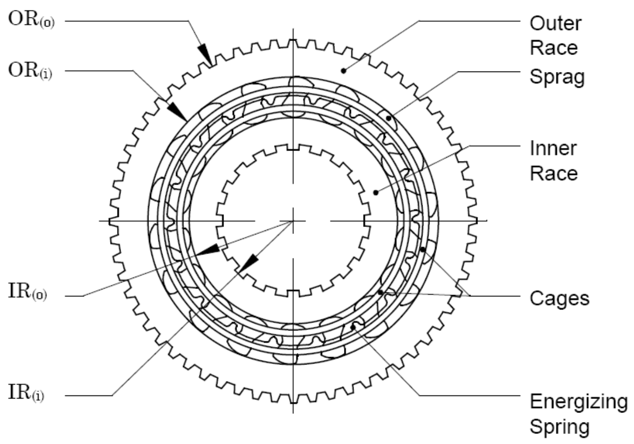


Figure 3. “sprag” OWC design (Chesney and Kremer, 1998).

According to Chesney and Kremer (1998) there are several advantages of a *sprag* OWC compared to a roller OWC. They highlights that a *sprag* OWC can operate at higher freewheel speeds and with lower drag, and generally has a high torque capacity for a given clutch volume. Besides, initial engagement is improved over a roller OWC due to the variability of the strut angle. Same authors pointed out, on the other hand, some disadvantages of *sprag* One-Way Clutches compared to roller OWC design such as: *sprag* OWCs are historically more expensive to manufacture and have lower cam, race, and eccentricity tolerances.

3. THE ROLLER FLOAT CONDITION

In the OWC dynamic performance the study of the roller float condition can improve product durability by avoiding excessive contact between roller and race, components responsible for the torque transmission. Considering the *roller float condition* happens because the OWC in motorcycle starters is permanently engaged to the engine crankshaft and this can lead to a potential failure mode due to the premature wear of the components in contact, this is an important design condition to be considered during product development.

As described in the research carried by Kremer (1995), when the outer race of a roller OWC freewheels about its axis and the clutch has an outer cam design, the rollers will revolve with the outer race. As a result of this motion the roller accelerates towards the center of rotation to maintain its position relative to the outer race. This is known as *centripetal acceleration* and, by Newton’s second law, the force needed to create this acceleration is defined by Eq. (1).

$$P_{cen} = m_{(r)}a = m_{(r)}c\omega_{(o)}^2 \quad (1)$$

Equation (1) defines $\mathbf{P_{cen}}$ as the roller centrifugal force, $\mathbf{m_{(r)}}$ is the roller mass, **a** is the roller acceleration, **c** is the distance from the center of the clutch to the center of the roller, and $\boldsymbol{\omega_{(o)}}$ is the angular velocity of the outer race. The resulting system of forces is shown in Fig. 4.

There exists an outer race speed above which the centrifugal roller force P_{cen} overcomes the spring force P_{sp} and the roller loses contact with the inner race. This condition is called by Kremer (1995) as *centrifugal roller float*.

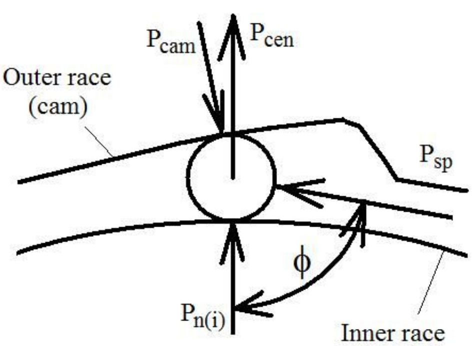


Figure 4. Forces acting on the roller for the centrifugal roller float analysis. Adapted from Kremer (1995).

4. LUMPED PARAMETER MODEL

A lumped parameter model was developed using commercial software LMS Imagine.Lab AMESim (Silva, 2005). This software aids the simulation of lumped parameter models which can represent complex multi-domain systems.

The model developed for the roller float analysis is represented by the sketch presented in Fig. 5. The modeling of the roller float condition was based in a single roller analysis. A practical OWC has always more than one roller, but this simplification can be adopted as the roller float condition has the same behavior assuming equal design parameters in every cage of the OWC.

The model was constructed to simulate the displacement of the roller when the outer cam is increasing its angular velocity. It computes the centrifugal force generated by the rotational speed of the outer race while monitoring the elastic contact between the roller and the inner race, which is the focus of the investigation. Roller mass and cam spring data were also considered in the model shown in Fig. 5. Those are the main variables determined to influence the roller float condition. Other variables might influence this behavior as well, such the fact of the OWC in motorcycle starter systems works immerse in engine lubricating oil. This condition may modify the friction coefficient in the roller-race interface, originally modeled as a dry steel-steel contact, or may reduce the resulting centrifugal force. Further investigation should be performed, but the determination and validation of this influence is a very challenging task and was not investigated so far. Nevertheless, initial durability tests of the OWC confirm the accuracy of the simulation results and indicate that the *roller float* condition is not very sensitive to this variable as no wear in the roller or race surfaces were found in samples after durability tests (see section 5 for details about durability test results).

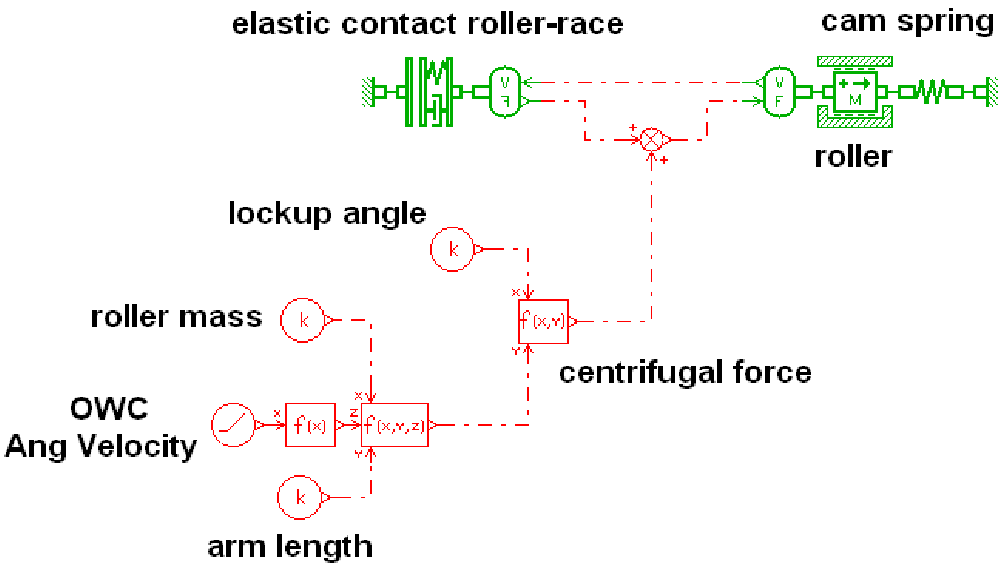


Figure 5. Lumped parameter model developed to study the roller float condition.

The *roller* model indicated in Fig. 5 computes the roller mass as well as the coefficient of viscous friction between the roller and the inner race. It also defines an end stop setting as the roller reaches the cam profile in the outer race. The OWC *angular velocity* comes from the electric motor and is an input to the *roller float* model defined as a linear ramp from zero to a maximum value that depends on each motorcycle starting system specifications. This condition is adequate for the model objective. Certainly, in a more complex model, to study the complete motorcycle starting system, the angular velocity should be a state variable resulting from the angular acceleration and not only an input data. Additionally, the *spring* model comprehends the spring stiffness and the initial spring force.

5. SIMULATION RESULTS

The simulation was performed using a starter OWC made by ZEN S.A. manufacturer, shown in Fig. 6, for Honda CG 125cc motorcycle electric starter systems.

Figure 6. Starter OWC for Honda CG 125cc motorcycle (Courtesy: ZEN S.A.)

The design parameters that influence roller float were determined in the work done by Kremer (1995) and are listed in Tab. 1. The simulation was defined considering a linear variation of angular velocity from 0 to 10^4 RPM.

Table 1. Design variables of Honda CG 125cc motorcycle starter OWC made by ZEN S.A.

Design specification (units)	Nominal value
Roller mass (g)	2.2
Spring stiffness (N/m)	123
Lockup angle (degrees)	3.46
Race diameter (mm)	42.0
Roller diameter (mm)	6.0
Initial spring force (N)	0.8
Arm length (mm)	25.835

Figure 7 shows the roller contact behavior related to the angular velocity of the OWC. At 3400 RPM it can be noticed that there was no evidence of roller float. Just after this limit the roller has initiated to experience floating, indicated by the displacement of the roller (different than zero) indicated in Fig. 7. At 3500 RPM the roller displacement simulated was 0.12mm and at 5000 RPM it was at its maximum displacement, hitting the end stop in the outer cam profile.

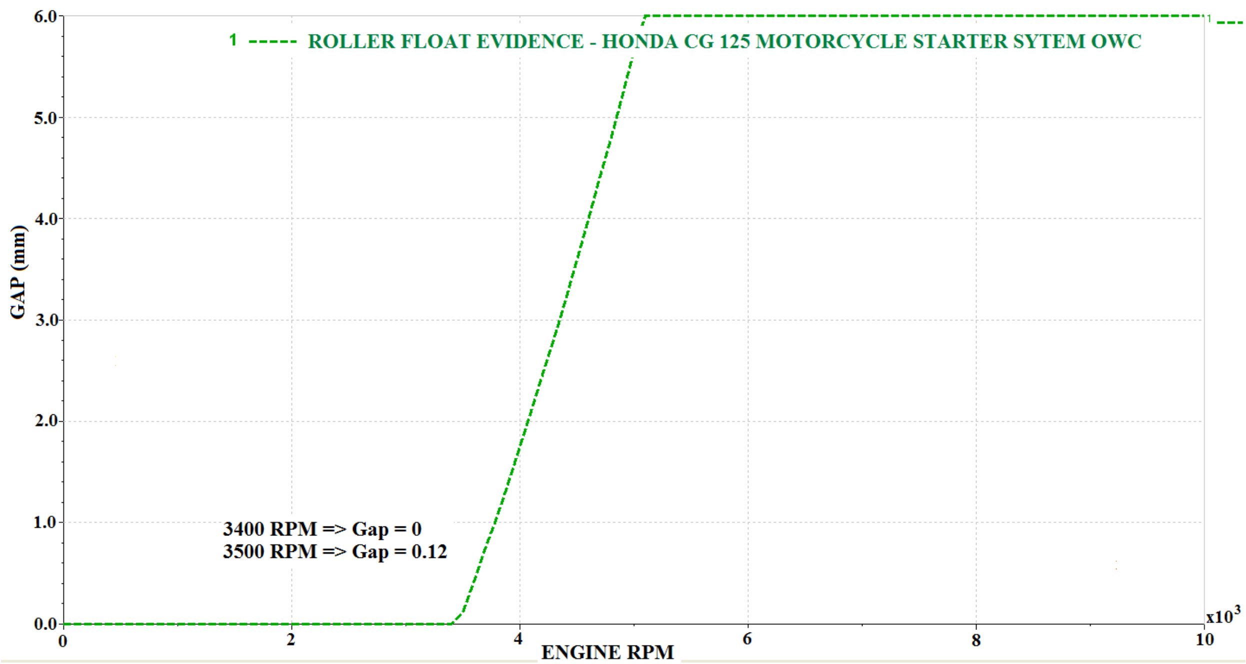


Figure 7. Simulation of the roller float condition for the Honda CG 125cc motorcycle made by ZEN S.A.

Additionally, a field test was carried with a sample. The OWC sample was installed in a delivery service motorcycle and a total of 16,000 km were accumulated. The working conditions vary from huge traffic jams (higher engine temperatures) to highway cycles (high engine torque and rotation). Before this test the starter OWC was put in a engine bench to verify the lockup torque capacity. The OWC was started up for 10,000 cycles, with higher severity defined by 2 s of cranking time and 1 s of overrunning period. After this successful test completion the field test was carried through. Figure 8 shows the main components of the OWC after the durability test. The rollers, springs and outer race show no wear or damage.

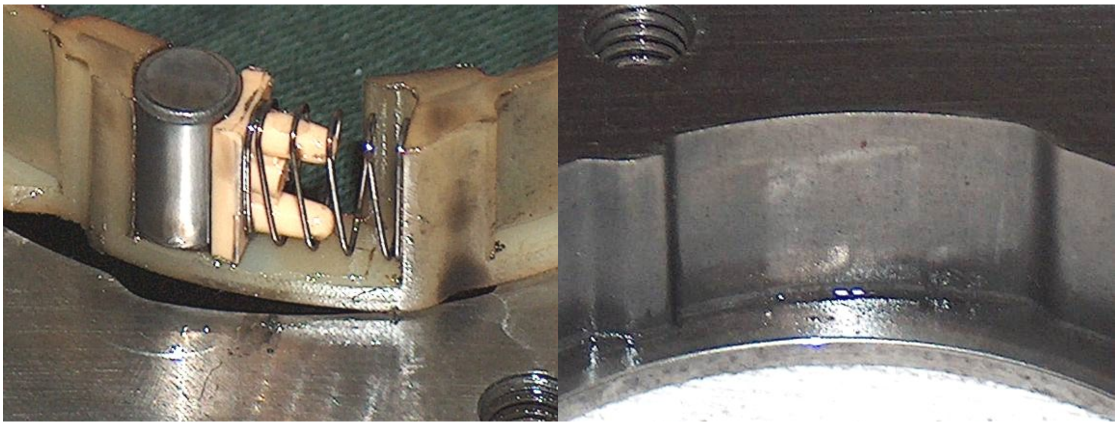


Figure 8. Components of the OWC made by ZEN S.A. after field durability test, no signs of wear or damage.

6. EXPERIMENTAL VALIDATION

In order to confirm the simulation results a starter OWC sample for a Yamaha YBR 125cc motorcycle (2001-2005) was tested in a rotating device to investigate roller float behavior. The OWC has design parameters that influence roller float as indicated in Tab. 2.

Table 2. Design variables of Yamaha YBR 125cc motorcycle (2001-2005) starter OWC.

Design specification (units)	Nominal value
Roller mass (grams)	6.0
Spring stiffness (N/m)	124
Lockup angle (degrees)	3.53
Race diameter (mm)	42.0
Roller diameter (mm)	9.935
Initial spring force (N)	0.8
Arm length (mm)	25.97

To perform the simulation the lumped parameter model was set to linearly vary the input angular velocity of the system from 0 RPM to 4000 RPM. Figure 9 presents the simulation result of the roller contact related to the angular velocity of the starting system. At 1950 RPM it can be noticed that there is no evidence of roller float. Just after this limit the roller initiates to experience floating, indicated by the contact gap (greater than zero). At 2500 RPM the roller displacement simulated is 4.14mm and at 2860 RPM it reaches its maximum displacement, hitting the end stop in the outer cam profile.

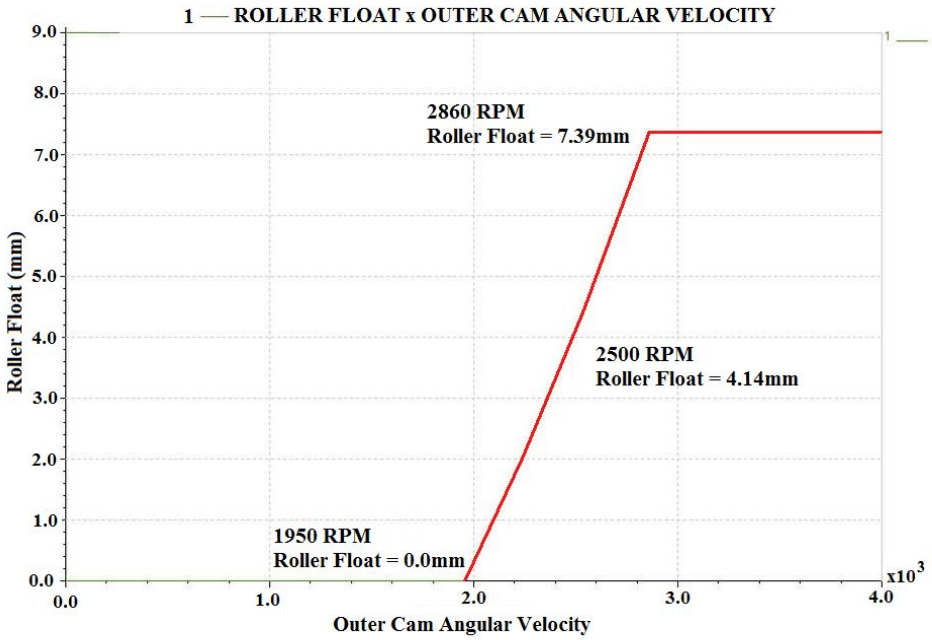
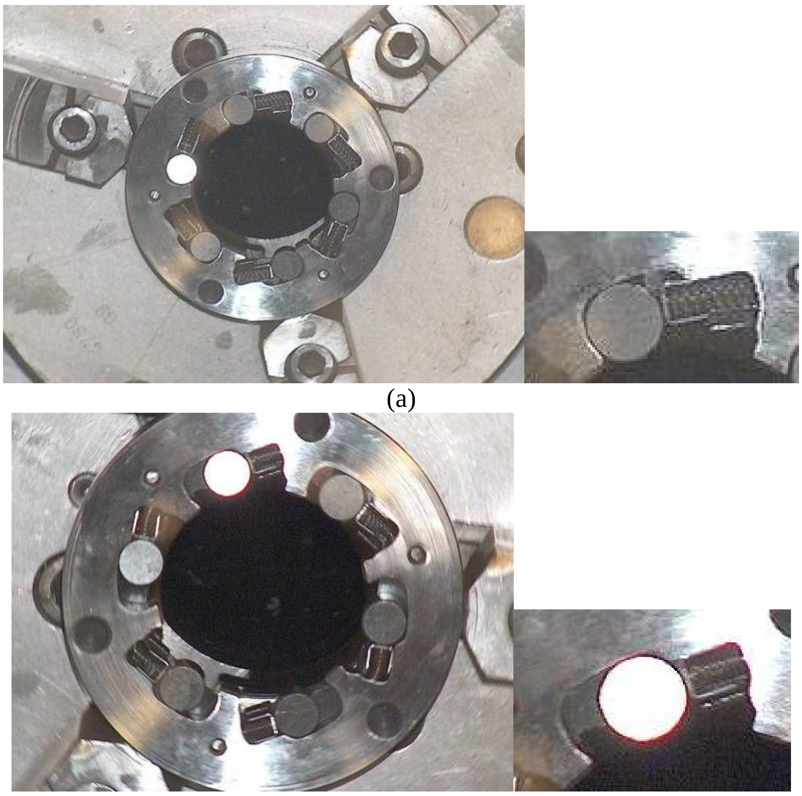


Figure 9. Simulation of the roller float condition for the Yamaha YBR 125cc motorcycle OWC.

To confirm the simulation result a sample of the OWC was fixed in the rotating device and it was set to spin at increasing angular velocity steps. The steps chosen were 1500, 2000, 2500 and 3000 RPM. The roller position was recorded and shown in Fig. 10. It was noticed the experimental evidence of roller float condition only above 2500 RPM for this One-Way Clutch. Therefore, the experiment confirms the simulation results of the lumped parameter model.



(a)

(b)

Figure 10. Experimental validation of roller float condition. Rotating speeds at (a) 2000 RPM and (b) 2500 RPM.

In the experiment, the inner race is not assembled as it would prevent the visual detection of the roller float condition. But the roller remains in contact with the cam edge due to the spring force until the point the centrifugal force of the roller overcomes the spring force. At that point the roller moves against the spring, and this considered the *roller float* phenomena that can be seen in Fig. 10 at 2500 RPM.

7. DESIGN IMPROVEMENT

The use of the lumped parameter model developed to simulate the roller float condition in OWC can improve design variables in order to modify the angular velocity threshold in which roller float starts to be detected. And it can be done earlier in the Product Development Process (PDP), reducing project lead time and cost. Each prototype failure for final product validation usually represents additional 30 days in project lead time. Failure represents additional cost to provide new samples as new tooling and prototype construction is necessary. The estimate for the starter OWC is that each new prototype represents additional US$2000 in project budget.

An investigation of the roller OWC developed by ZEN S.A. for an OEM (Original Equipment Manufacturer) motorcycle starter system application was carried through the lumped parameter model. Table 3 indicates the initial design specifications.

Table 3. *Initial* and *Proposed* design of the OEM motorcycle starter OWC.

Specification (units)	Initial Design	Proposed Design
Roller mass (g)	2.2	2.2
Spring stiffness (N/m)	123	**61.5**
Lockup angle (degrees)	2.39	**3.8**
Race diameter (mm)	49.716	49.716
Roller diameter (mm)	6.0	6.0
Initial spring force (N)	0.91	**0.5**
Arm length (mm)	27.858	27.858

The simulation based on the Initial Design shows the roller float starts only above 4000 RPM as indicated in Fig. 11. This condition cannot be considered adequate regarding product performance as the idle speed of the engine is much lower than that value, around 1400 RPM. Based on the simulation, roller and race remain in contact up to 4000 RPM, potentially leading to excessive wear and negatively affecting roller OWC performance.

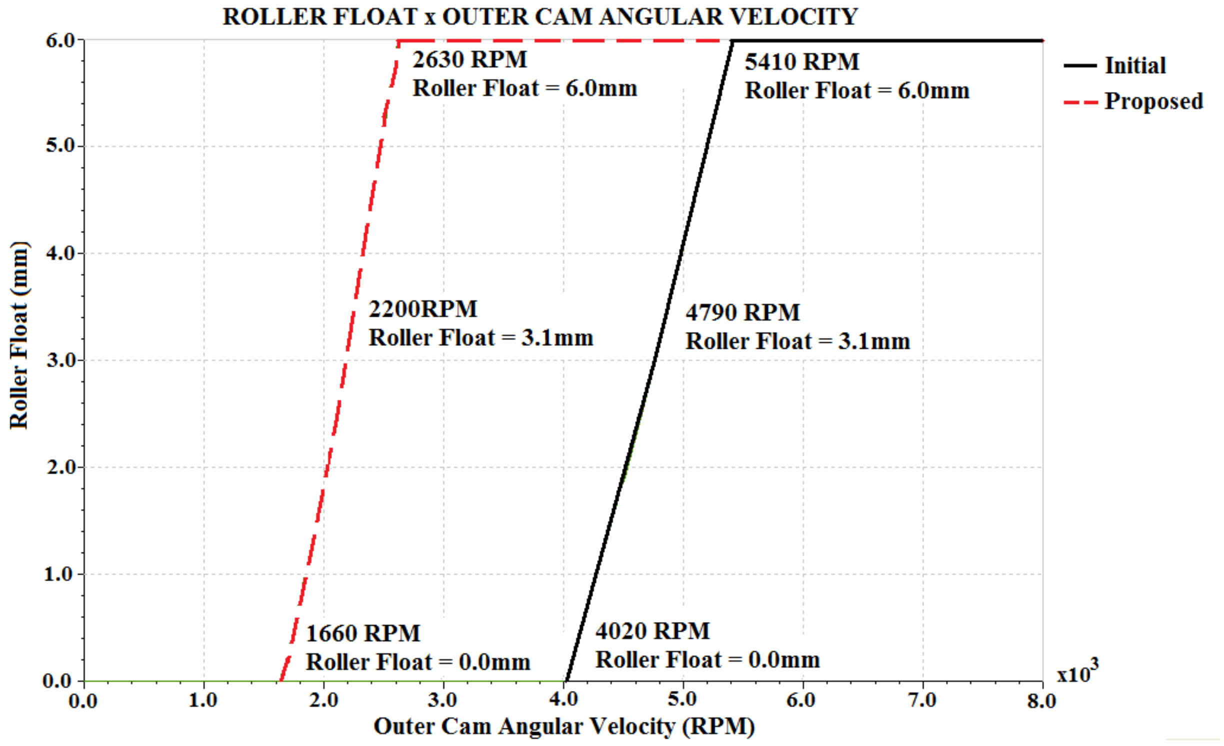


Figure 11. Simulation of the roller float condition in OEM OWC (Initial and Proposed Design).

Considering that the roller and race dimensions cannot be changed due to packaging constraints a *Proposed* design parameters set is based on changes to the lockup angle and spring stiffness and initial force, as shown in Tab. 3.

Fig. 11 also shows the results from the Proposed Design. The roller float starts above 1660 RPM and hits the end stop at 2630 RPM. Considering the idle speed of the OEM application is around 1400 RPM the proposed design is very adequate as prevents excessive wear and improve system durability.

8. CONCLUSIONS

This work shows that the dynamic simulation of the roller float condition has the potential to improve One-Way Clutch design applied to motorcycle starter systems.

The dynamic simulation of the lumped parameter model was validated by comparing the simulation results to experimental investigation. The validation confirms the accuracy of the model and its application to the design and improvement of OWC motorcycle starting systems.

Furthermore, considering that each prototype failure during final product validation usually represents additional 30 days in project lead-time and additional cost around US$2000 in project budget, the approach presented in the paper can be done earlier in the Product Development Process (PDP), reducing project lead time and cost.

9. REFERENCES

Akagi, M.; Hosoda, W. “One Way Clutch”, Honda Giken Kogyo Kabushiki Kaisha, Tokyo, Japan. Int Cl F16D41/07.US.PI 5038903. Aug. 13, 1991. Available at http://www.freepatentsonline.com/5038903.html. Access in 02/16/09.

Chesney, D.; Kremer, J. Generalized Equations for Roller One-Way Clutch Analysis and Design. SAE International Paper nr. 970682, 1997.

Chesney, D.; Kremer, J. “Generalized Equations for Sprag One-Way Clutch Analysis and Design”, SAE International Paper nr. 981092, 1998.

Kremer, J. “Roller Float as a Consideration in Outer-Cam, Roller One-Way Clutch Design”, SAE International Paper nr. 950670, 1995.

Ouchi, Y. “One Way Clutch”, Yamaha Hatsudoki Kabushiki Kaisha, Iwata, Japan. Int Cl F16D41/06.US.PI 5099972. Mar. 31, 1992. Available at http://www.freepatentsonline.com/5099972.html. Access in 02/16/09.

Silva, J.C. “Virtual Environment for Dynamic Modeling of Multi-Domain Systems”, 18th International Congress of Mechanical Engineering. Ouro Preto, Brasil, 2005.

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