Noise and vibration at start of the internal combustion engine - comparison between using a starter versus a BSG (belt starter generator)

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RESUME

Along with the trend towards hybridization and electrification of conventional vehicles with an internal combustion engine, the technologies integrated into the vehicles bring more comfort and well-being in several aspects. This study will show what the differences are when we apply a BSG (belt starter generator) to start the combustion engine, instead of starting it with a conventional starter.

Among the main functions of the BSG are: starting the internal combustion engine; generate energy to charge the battery; recover energy from the engine braking; work as an electric motor mode to assist the internal combustion engine; and Start-Stop function. This article will focus on the start of the combustion engine, which in this case (when using a belt starter generator) is made by the belt circuit instead of using the flywheel ring gear of the thermal engine, as it is done when the start is driven by the starter.

The results presented will be based on analyzes and tests performed in the laboratory based on comparisons made on vehicles that have been modified from their conventional base (starter + alternator) to a possible hybrid prototype vehicle with a BSG machine.

1. INTRODUCTION

Due to vehicle updates and guidelines for reducing noise and emissions of gases in the atmosphere, the tendencies are to change components to improve the performance of the thermal engine and its components, such as reducing noise during starts and noise related to the operation of the alternator under certain conditions. With that, the automakers are investing great values for the development of technologies and integration of components involving the entire powertrain, for vehicles with hybrid and even electric technologies.[1]

Emissions of noise and vibrations by vehicles are important and are measured and evaluated according to the law of each country. As such, it is extremely important to identify which components can generate the most noise, vibration. As a result, it is extremely important to carry out measurements and verify such phenomena that are generated electrically and mechanically by these components. Noise and vibration are directly linked when applied to the industrial pole, since there is a set of components that generate undesirable noises to the human ear through the constructive environment, these when they reach high levels of the sound frequency. Vibration is a consequence of movements that occur during the operation of the thermal engine and its components that are transmitted to the vehicle chassis and can also be perceived more or less frequently by the final customer. There are several ways to decrease or even mitigate such effects.

The objective of the article is to demonstrate a comparison between conventional starts in the thermal engine through the flywheel ring gear system and the result obtained after the substitution by the starting system through the belt, where the important greatness perceptible to the final customer were analyzed (noise and vibration).

1.1 STARTER

The starter is an electric machine with brushes that has the function of transforming electrical energy into mechanical energy inversely the function of the alternator when activated. Therefore, it is inoperative after performing this function on the starting system. The starter is powered by the B+ battery positive and driven by the ignition contact (starting system) according to the model in figure 1.

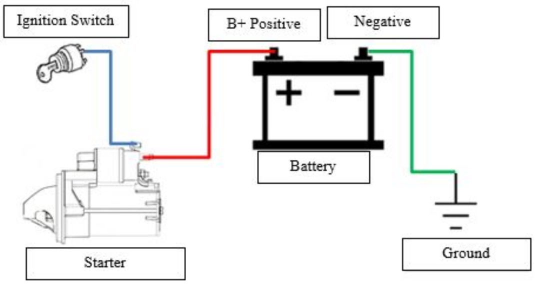

Figure 1. Example of a starting system

During operation, the solenoid is powered with a positive battery, pushing the mechanical assembly, which in turn slides the impeller until it engages with the flywheel ring gear at the same time the solenoid closes the main circuit, energizing the coil and the armature through the brush holder, creating a magnetic field and thus the rotation movement. This movement produces the initial torque to overcome the internal friction of the combustion engine guaranteeing the movement of the pistons and consequently the vehicle starts.

1.2 CONVENTIONAL ALTERNATOR

The automotive alternator is an electrical machine that is responsible for converting mechanical energy into electrical energy. It is powered by the vehicle battery that uses the energy generated by the pulley to rotate the rotor, which through electromagnetism transforms mechanical energy into electrical energy, in the form of alternating current. The stator in turn passes this energy to the diode rectifier bridge, which transforms the alternating current into direct current. Upon reaching the voltage regulator, the voltage generated by the alternator is restricted between 12.0V to 14.8V. From this moment on, the alternator is able to charge the vehicle battery and power all its peripherals. See model of an automotive alternator in figure 2.

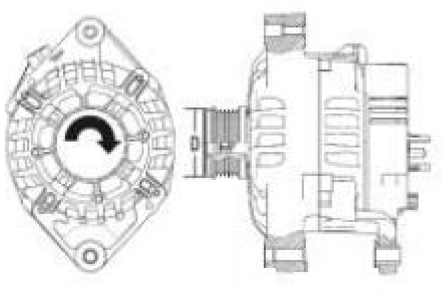

Figure 2. Example of an automotive alternator

1.3 BELT STARTER GENERATOR (BSG)

Currently in conventional vehicles the starting system is made through the starter, where when the key is activated it starts operating and when it is coupled to the flywheel ring gear it starts the movement of the pistons, generating the entire process already known until the thermal engine works. The current system is quite efficient and meets a large part of the needs, however with the new technologies and the reduction of thermal engines, these being increasingly technological, it is necessary to update the starting system.

The construction method of the BSG machine is similar to the conventional alternator, in which there is a pulley, front and rear brackets, a stator, a rotor, among others. The difference is in the control part of the machine because it uses electronic components (inverter, ICs and others) that are responsible for performing the communication and the controls together with the vehicle's ECU and generate the torque in its pulley, for example, during the initial starting system.[3]

The machine used for the comparison has among the most important the functions of generator, stater, regenerative braking, start and stop function and the ability to assist the performance of the thermal engine (booster). The technology uses the belt system that currently exists on the vehicle. The machine to be integrated has a high degree of reliability and robustness as seen in figure 3.

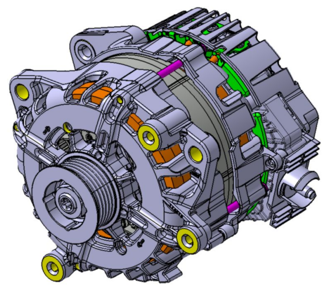

Figure 3. Used model of BSG 12-14Volts

1.4 NOISE

Every rotating component just like the alternator radiates noise at a frequency directly related to its mechanical structure (number of poles, number of slots), all noise from the components contributes to the general noise, when the rotation speed of the alternator increases the frequency the noise radiated by the components also increases. Thus generating magnetic, aerodynamic or mechanical noise. [4]

1.5 MECHANICAL VIBRATION

To understand the measurements made regarding vibration, one must understand the correct foundation on the phenomenon whereby definition vibration is due to the alternating movement of a solid body in relation to its center of balance; oscillation, balance.[5]

Such measurement can be performed by N instruments, which by constructive means returns us an output value when subjected to an input signal x, in the case of the article there is the acceleration in meters per second squared (m/s2). To obtain such values, there is a mathematical model that is already applied and currently facilitates measurements.

There are several classifications related to vibration, such as free, forced, damped, not damped, among others. For the application referring to the article, the result is forced vibration, where the system is subject to an external force (often repetitive) in the case of oscillation of the thermal engine. If the frequency of the external force coincides with one of the system's natural frequencies, a condition known as resonance occurs. This resonance is often associated with structural failures that occur in different materials and structures.

2. METHODOLOGY

Measurements are necessary to identify the current levels of noise, vibration, gas emissions in the atmosphere, among others during start-up and the operation of a vehicle, for example. This can be done through pre-established standards, where there is a procedure for making such measurements. With the data acquired during the start, it is possible to analyze the characteristics of the starter and the alternator, identifying the current levels of the generated noise.

These noises are recorded through a microphone that captures the generated waves and stores them using software. The standards follow standards according to each customer and the data is different for each type of component. In general, the test is performed as follows:

- The distance from the microphone to the component must be 50 mm;
- The measurements are carried out in 3 phases;
- Normal start;
- Normal start + freewheel;
- Without ignition.

The acquisition of the vibration of the alternator fixed to the thermal engine follows the pattern determined by each customer, generally following the steps of first fixing the accelerometer in the engine block and measuring the acceleration in three axes then fixing the accelerometer in the front support of the alternator and measure acceleration also on three axes.

For vibration tests, an accelerometer calibrated according to figure 4 is used, where it is possible to measure the acceleration of a system.

Figure 4. Model of uniaxial accelerometer ICP

3. RESULTS

3.1 STARTER/ CONVENTIONAL ALTERNATOR

The vehicle was subjected to 2 tests, acquisition of the vibration of the engine block and the alternator and noise evaluation in the starter. In the noise evaluation, the starter did not present abnormal noise during the subjective evaluation and in the objective measurement the noise values registered for the normal start were below the specified maximum (105dB) as seen in table 1. Ultrasounds show no signs of abnormalities.

Samples	Normal start				No Ignition			
	Global noise				Global Noise			
	Peak Hold		Linear		Peak Hold		Linear	
	dB	dB(A)	dB	dB(A)	dB	dB(A)	dB	dB(A)
-	102.6	103.0	98.8	99.2	105.7	106.0	91.2	90.9
Specified	---	---	<105	---	---	---	---	---

Table 1. Acoustic result in the starter

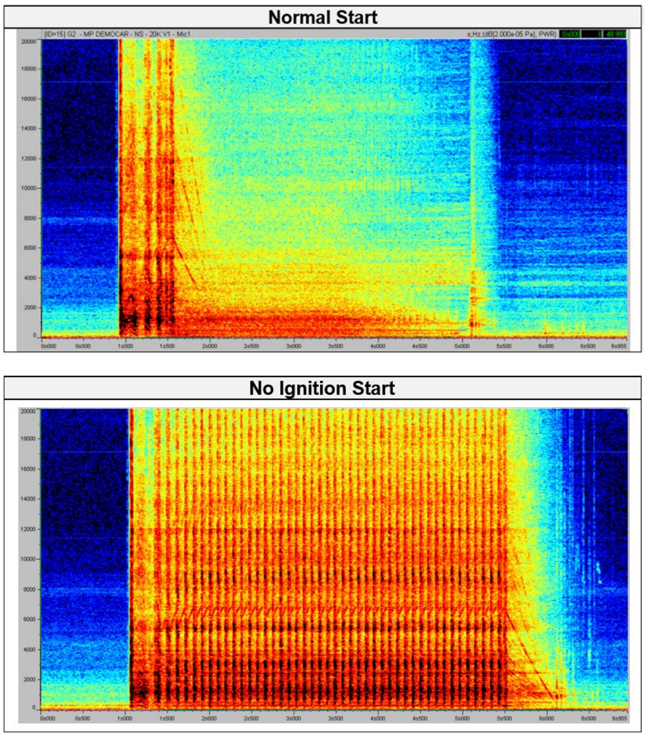

Figure 5. Sonogram analysis on the starter.

The vibration acquisition was evaluated with the vehicle stopped and with the thermal engine speed limited to (4000rpm).

Looking at the measurement graphs on the thermal engine block, it is possible to see that the order 1.5 on the Z axis becomes higher when the speed of the thermal engine is increased. In this case, the maximum displacement reached 0.009 mm. On the X and Y axes, it was not possible to identify any resonance in the alternator or in the block, perhaps this only occurs at speeds above 4000 rpm.

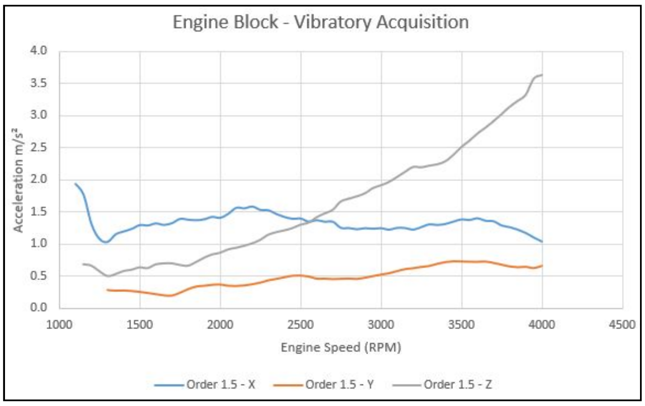

Figure 6. Acquisition of vibration in the thermal engine block

In the alternator measurement, it is possible to see an interrupted downward trend of around 3250 rpm for the Y axis. Also on the X axis, for the measurement of the engine block, there is an abnormal peak at low speed (1100 rpm), this peak is unexpected, but it appears in both evaluations made in this condition. In any case, these peaks do not represent resonance. The evaluated order is 1.5, because the vehicle has a 3-piston engine.

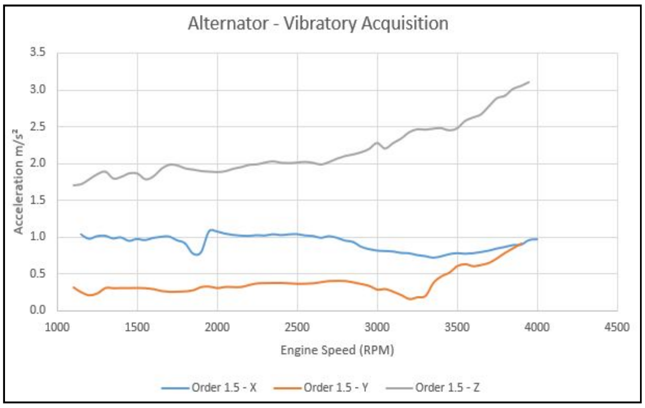

Figure 7. Acquisition of vibration in the Alternator

3.2 BELT STARTER GENERATOR (BSG)

In the same way as for conventional components, the BSG was subjected to the same tests. In the noise assessment, it is possible to verify that the belt starter generator has lower noise values. In the evaluation of the normal start, the noise difference reached 24dB (A) for the peak and the linear noise. For the evaluation without ignition, this difference was 17.6dB (A) for linear and 24.5dB (A) for the peak, as seen in Table 2. The big difference can also be observed in ultrasounds.

Samples	Normal start				No Ignition			
	Global noise				Global Noise			
	Peak Hold		Linear		Peak Hold		Linear	
	dB	dB(A)	dB	dB(A)	dB	dB(A)	dB	dB(A)
BSG	90.8	78.5	85.7	74.3	89.3	81.5	80.1	73.3
Specified	---	---	<105	---	---	---	---	---

Table 2. Acoustic result in the BSG machine

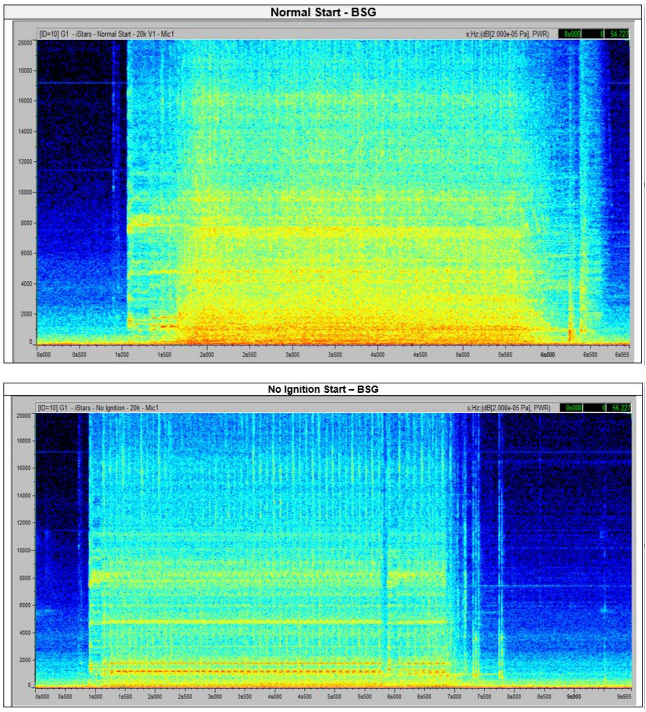

Figure 8. Sonogram analysis on the BSG

The most important order for the acquisition is 1.5, but this order did not show the expected values. The extracted orders were the general, 1.5, 3.0, 4.5 and the order 6.0 and as expected the highest value is the general, but the highest order is order 6. In the first acquisition (when the car was assembled with hexaphasic alternator and the starter) the values found reached 3g for the order 1.5, but for the acquisition in the reversible alternator, 1.2g were found for the machine and 0.7 in the block.

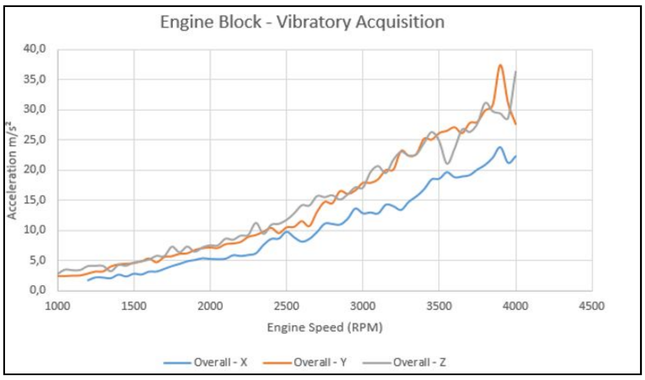

Figure 9. Acquisition of vibration in the thermal engine block

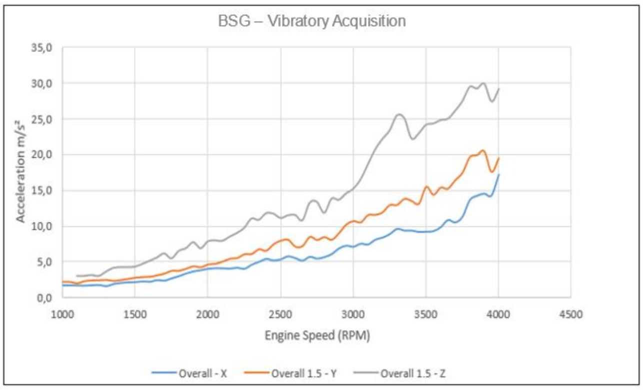

Figure 10. Acquisition of vibration in the BSG

4. CONCLUSION

In the general comparison, it is possible to identify a relevant difference in vibration before and after the assembly of the BSG machine, where it presented higher values of general vibration in the block for the three axes of the compared to the acquisition made with the 120 Ampere hex phasic alternator and higher values on the X and Z axes for the acquisition of vibration in the engine block according table 3.

Vibration on the machine (g)					
BSG	Conventional Alternator	BSG	Conventional Alternator	BSG	Conventional Alternator
X (Peak)		Y (Peak)		Z (Peak)	
17.18	8.08	20.39	47.85	29.82	19.15

Vibration on the engine block (g)					
BSG	Conventional Alternator	BSG	Conventional Alternator	BSG	Conventional Alternator
X (Peak)		Y (Peak)		Z (Peak)	
23.88	4.97	37.53	6.22	36.33	6.46

Table 3. Vibration results comparative between Conventional Starter X BSG Machine

Regarding noise, BSG machine had lower noise values, and this is noticeable in the subjective and objective evaluation. Also is observed lower values in the normal start, without ignition described in table 4.

Samples	Normal start				No Ignition			
	Global noise				Global Noise			
	Peak Hold		Linear		Peak Hold		Linear	
	dB	dB(A)	dB	dB(A)	dB	dB(A)	dB	dB(A)
Conventional Starter	102.6	103.0	98.8	99.2	105.7	106.0	91.2	90.9
BSG Machine	90.8	78.5	85.7	74.3	89.3	81.5	80.1	73.3
Difference	11.8	24.5	13.1	24.9	16.4	24.5	11.1	17.6
Specified	---	---	<105	---	---	---	---	---

Table 4. Acoustic results comparative between Conventional Starter X BSG Machine

The noise difference reached 24.5dB (A) for the peak and 24.9dB (A) for the linear noise compared to the conventional starter. For the evaluation without ignition, this difference was 24.5dB (A) for peak and 17.6dB (A) for linear. The big difference can also be observed in ultrasounds.

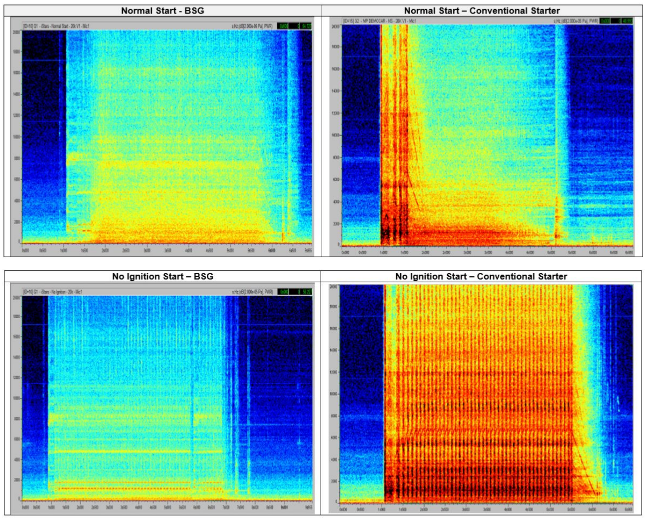

Figure 11. Sonogram analysis comparative between Conventional Starter X BSG Machine

In view of the results, it is possible to verify that the BSG machine has great advantages, such as generating less noise when starting and running, bringing more comfort to the user.

5. REFERENCES

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