

# Research in the field of vibration of automotive systems

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**Abstract.** The aim of the research is to improve knowledge about the behaviour of materials and structures, to develop models and tools useful in the process of design of structures and machines and to capitalize on a technical culture in terms of analysis, design and manufacturing methodologies. We also set out to show the influence of which types of vibrations have an effect on the operation of the crankshaft mechanism of a car engine, as well as their influence on the operation of the camshaft system, all of which are taken into account in any design process in this field. The generalization of the theory of elasticity and the dynamics of viscous fluids led to the creation of the linear theory of viscos-elasticity, the bodies with such a behaviour obeying the principle of overlapping Boltzmann. Thus, mechanical models were built consisting of spring and damping systems, the springs describing the elastic properties of the body, and the dampers on the viscous ones.

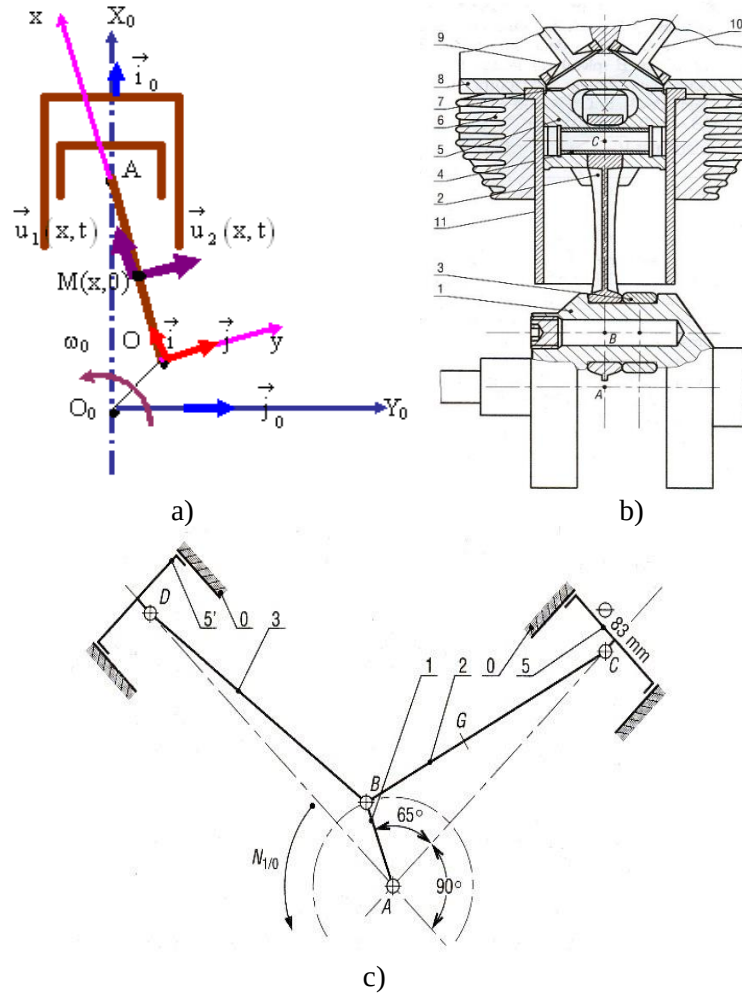
## 1. Introduction

A high level of safety calculations can ensure the use of multiple systems of computational mathematics, what we see in this work by comparing graphs that we obtained using two computers where cam follower system. The trend of replacing metallic materials with materials with rheological behaviour also belongs to the current field, the latter having a series of advantages, one of them being very important, being that of the existence of reduced forces and inertia torques due to the lower specific mass, compared with metallic materials under comparable stiffness, which appears in this work. Currently, research activities focus on the development of multidisciplinary experimental, theoretical and numerical skills put into play when designing structures, machine elements or, in general, mechanical systems [1, 2, 3]. The aim of the research is to improve knowledge about the behaviour of materials and structures, to develop models and tools useful in the process of design of structures and machines and to capitalize on a technical culture in terms of analysis, design and manufacturing methodologies [4, 5, 6]. This research is supported by the fields of materials science, nonlinear mechanics of solids, fluids and coupled systems, acoustics, forming and processing techniques, experimental measurement methods and numerical modelling. Research in the field of vibrations is the subject of research of numerous articles, focused especially on vibrations in gears, suspension systems for vehicles [7-15].

## 2. Vibrations of the crankshaft mechanism

Figure 1a show the mechanical model of the crank connecting rod mechanism of a motor subjected to transverse and longitudinal vibrations. Figure 1b shows the coupling of an engine with a layout, which consists of the crankshaft 1, the connecting rods 2 and 3, the two pistons and with the bolts 4, the cylinder

head 7 (8), the cylinder liner 11 with the cooling fins 6 and inlet and outlet valves 9 respectively 10. The device occupies the position in figure 1c.



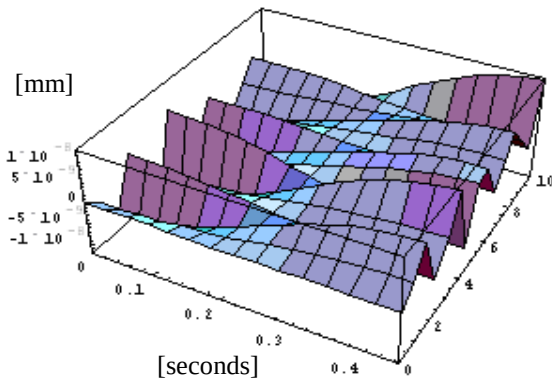
**Figure 1.** The crankshaft mechanism of an engine.

Let be the laws of definition of the longitudinal and transverse displacements of the viscoelastic connecting rod, respectively:

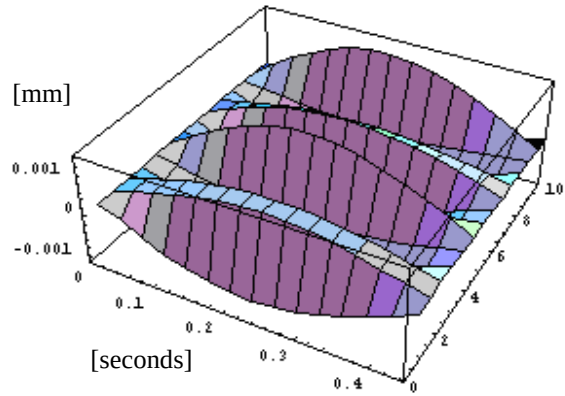
$$u_1^{(1)}(x, t) = a_1 + a_2 \cdot \cos^2(\omega_0 t) + a_3 \cdot \cos(\omega_0 t) + \frac{2}{L} \cdot \sum_{n=1}^{\infty} [a_{1,n} + a_{2,n} \cdot \cos^2(\omega_0 t) + a_{3,n} \cdot \cos(\omega_0 t) + a_{4,n} \cdot \cos(\omega_{n,1} t)] \cdot \cos(\alpha_n x), \quad (1)$$

$$u_2^{(1)}(x, t) = \frac{2b}{L} \sum_{n=1}^{\infty} \frac{1}{b_n} \left[ \left( \sum_{j=1}^4 b_{j,n} \right) \sin(\omega_0 t) + (b_{5,n} + b_{6,n}) \sin(2\omega_0 t) + \left( \sum_{j=1}^4 c_{j,n} \right) \sin(\omega_{n,2} t) \right] \cdot \sin(\alpha_n x) \quad (2)$$

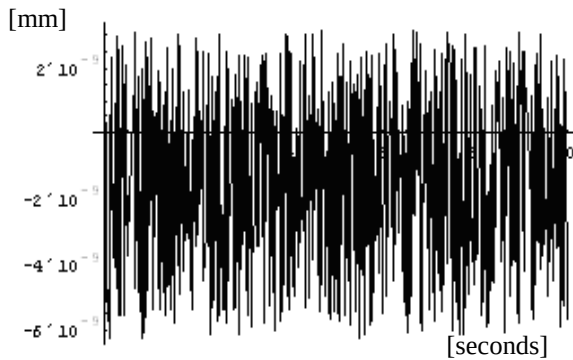
Consider the specific case of an internal ignition engine in which:  $L=L_b=0,164$  m, is the connecting rod length;  $r=0,043$  m, is the crankshaft radius;  $\omega_0 = 680,333 \text{ s}^{-1}$ , is the crankshaft angular velocity;  $I_{zz}=7376,28 \text{ mm}^4$ , is the connecting rod moment of inertia ;  $\rho = 7800 \text{ Kg/m}^3$ , is the rod specific mass;  $E=2,1 \cdot 10^{11} \text{ N/m}^2$ , represents the Young's modulus;  $A=283,68 \cdot 10^{-6} \text{ m}^2$ , is the connecting rod cross section. With the laws of definition (1), (2) and with the above concrete data results, with the Mathematica program, the graphical representations from figures 2, 3, 4, 5, of the functions  $u_1 = u_1^{(1)}(x, t)$ , the longitudinal displacements,  $u_2 = u_2^{(1)}(x, t)$ , the transversal displacement,  $u_1 = u_1^{(1)}\left(\frac{L}{3}, t\right)$ , respective  $u_2 = u_2^{(1)}\left(\frac{L}{3}, t\right)$ , in a first approximation.



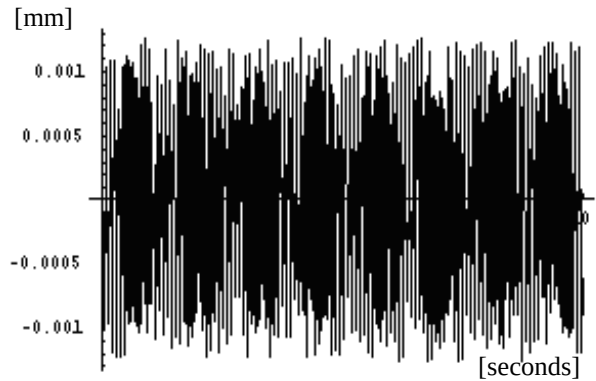
**Figure 2.** Graphical variation of displacement  $u_1$ , plotted in Mathematica software.



**Figure 3.** Graphical variation of displacement  $u_2$ , plotted in Mathematica software.

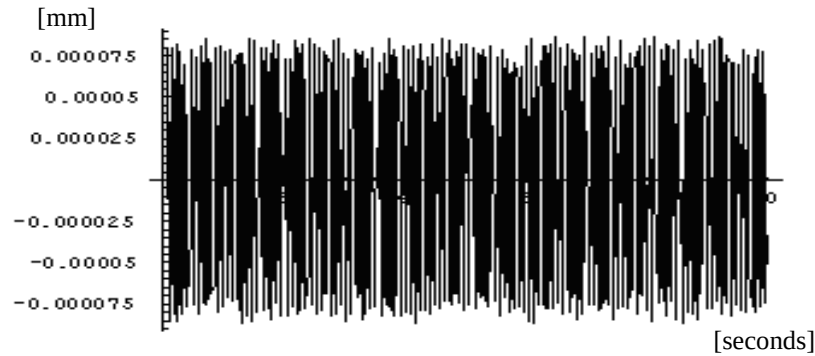


**Figure 4.** Graphical variation of displacement  $u_1$ , plotted in Maple software.



**Figure 5.** Graphical variation of displacement  $u_2$ , plotted in Maple software.

Stopping the iterative process at the third approximation, the graphical representation of the transverse displacement function at the abscissa point results  $x = L/3$ , from figure 6.

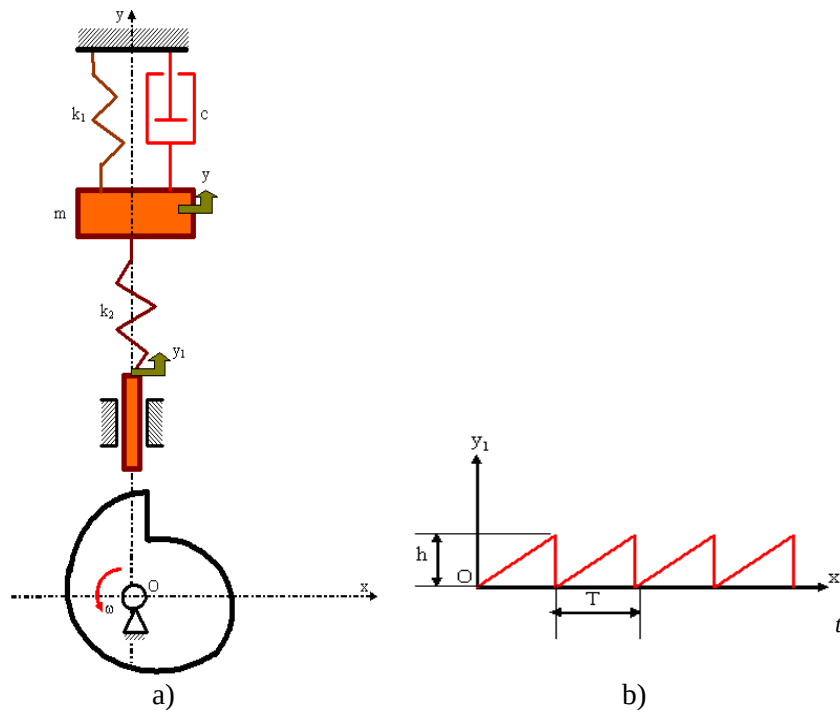


**Figure 6.** Graphical variation of displacement  $u_2$ , for  $x = L/3$ , plotted in Maple software.

As can be seen, the field of longitudinal displacements has a negligible influence, which is why we continued the iterative process only for transverse displacements. As the displacements are very small, it is convenient to give up ferrous materials, the materials with such behaviour being much cheaper.

### 3. Cam-follower system vibration

The vibrating system actuated by the cam in figure 7a is considered.



**Figure 7.** The mechanical model of the cam-driven vibrating system.

The lower end of the spring of elastic constant  $k_2$  has the function of follower, being driven by a cam rotating at a constant angular velocity  $\omega$  and having a sawtooth-type law of motion, with the maximum displacement  $h$ , as in figure 7 b. In the figure 7b the time variable  $t$  was denoted by  $x$ , notation that will

use further. In Lagrange's or Newton's formalism we obtain the mathematical model of the motion of the mass body  $m$  (valve):

$$m\ddot{y}(t) + c\dot{y}(t) + k_1y(t) + k_2[y(t) - y_1(t)] = 0 \quad (3)$$

or, in other words:

$$\ddot{y}(t) + 2n\dot{y}(t) + \omega_n^2y(t) = \varpi_n^2y_1(t) \quad (4)$$

where:  $k_e = k_1 + k_2$ ,  $\frac{c}{m} = 2n$ ,  $\frac{k_e}{m} = \omega_n^2$ ,  $\frac{k_2}{m} = \varpi_n^2$ ,  $c$  being the damping constant.

The law of motion of the cam for a period  $T$  is:

$$y_1(t) = \frac{h}{T}t, 0 < t < T \quad (5)$$

so that the mathematical model (4) takes shape:

$$\ddot{y}(t) + 2n\dot{y}(t) + \omega_n^2y(t) = \varpi_n^2\frac{h}{T}t. \quad (6)$$

Consider a numerical application in which:  $m = 1Kg$ ,  $h = 0,05\text{ m}$ ,  $T = 1\text{ s}$ ,  $k_1 = 300\frac{N}{m}$ ,  $k_2 = 20\frac{N}{m}$ ,  $c = 15Nsm^{-1}$ , so that the equation (6) become:

$$\ddot{y}(t) + 15\dot{y}(t) + 320y(t) = t. \quad (7)$$

Applying to equation (7) the unilateral Laplace transform with respect to time, under the initial conditions  $y(0) = 0$ ,  $\dot{y}(0) = 1\left[\frac{m}{s}\right]$ , the algebraic equation results:

$$s^4\tilde{y}(s) - s^2 + 15s^3\tilde{y}(s) + 320s^2\tilde{y}(s) = 1 \quad (8)$$

with the solution:

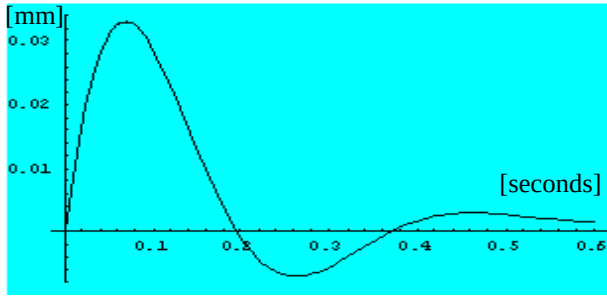
$$\tilde{y}(s) = \frac{s^2 + 1}{s^2(s^2 + 15s + 320)}. \quad (9)$$

Inverting in (9), in the *Mathematica* calculation system, results the solution of equation (7) in the form of the time function:

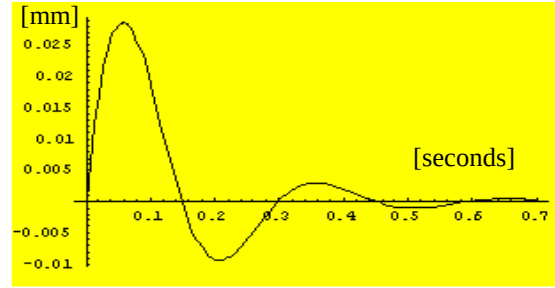
$$y(t) = \frac{1}{21606400} \cdot \quad (10)$$

$$\cdot \left\{ -3165 + 67520t + e^{-\frac{15}{2}t} \left[ 3165 \cos\left(\frac{\sqrt{1055}}{2}t\right) + 40877\sqrt{1055} \sin\left(\frac{\sqrt{1055}}{2}t\right) \right] \right\}$$

whose representation is given, in the same calculation system, in figure 8:



**Figure 8.** Mathematica representation of  $y$  function.



**Figure 9.** Maple representation of  $y$  function.

In the *Maple* software, the time function is obtained as in equation (11), and plotted in figure 9.

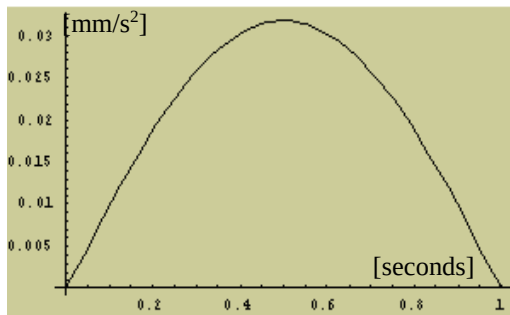
$$y(t) = e^{-7,5t} [0,6186 \cdot 10^{-5} \cos(21,0653t) + 0,0047 \sin(21,0653t)] + e^{-0,3921 \cdot 10^{-107}} [0,000064 \sin(3,1415t) - 0,6186 \cdot 10^{-5} \cos(3,1415t)] \quad (11)$$

We presented only the first harmonic because, for the chosen numerical data, the variation of the function  $y = y(t)$  according to the number of harmonics used is not significant. As we have shown above, a high level of computational security can be ensured by the use of several systems of computational mathematics, which we observe in this example by comparing the two graphs we obtained using two computational systems. The periodic function  $y_1 = y_1(t)$ , given by the law of definition (5), is decomposed into the Fourier series:

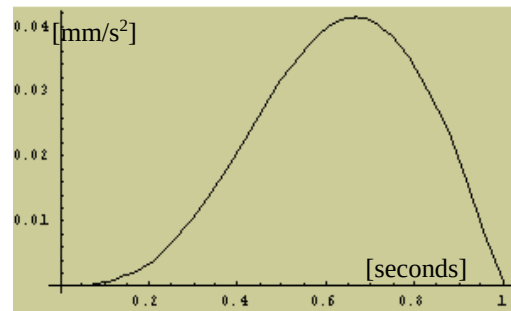
$$y_1(t) = \sum_{i=1}^n a_i \sin(i\pi t) \quad (12)$$

where:  $a_1=0,03183$ ,  $a_2=-0,01591$ ,  $a_3=0,01061$ ,  $a_4=-0,00795$ ,  $a_5=0,00636$ ,  $a_6= - 0,005305$ .

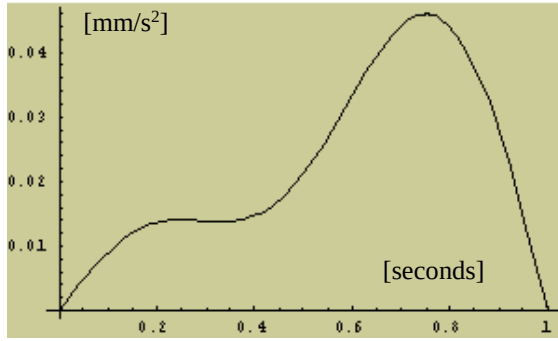
The considered decomposition presenting terms only in the sine function, it being obtained by using the *Maple* calculation system. The following figures show this decomposition, observing the effect that the number of terms, taken into account, has on this dependence. Consideration of several terms makes the representation of the function  $y_1 = y_1(t)$  as relevant as possible. In our application it is observed that, starting from the representation of even the first 15 harmonics, the variation of this dependence depending on the number of harmonics used is no longer significant. However, if we take a concrete example, such as the valves of an internal ignition engine, it requires the consideration of over 150 harmonics.



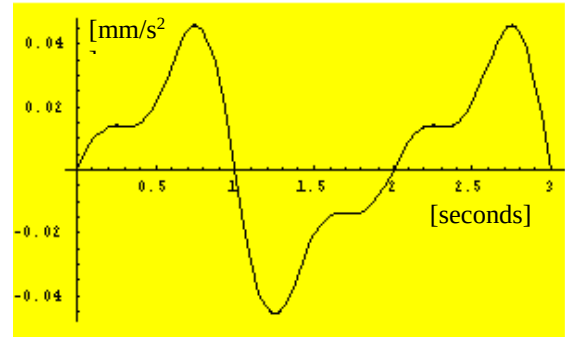
**Figure 10.** Representation of the first harmonic.



**Figure 11.** View of the first two harmonics.

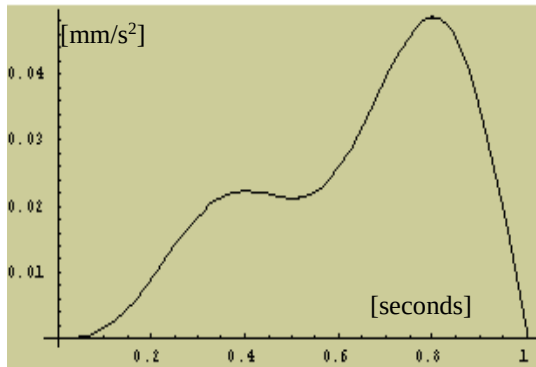


a) For 1 second

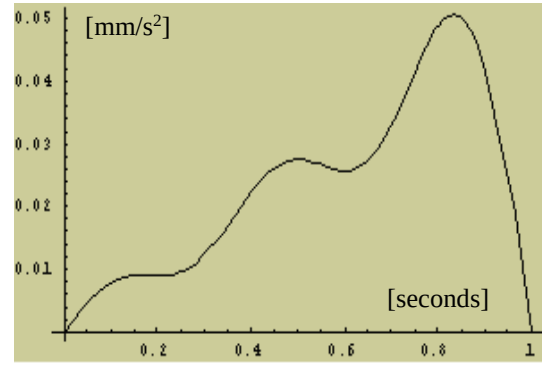


b) For 3 seconds

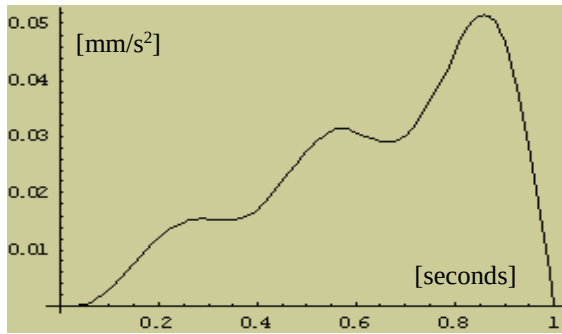
**Figure 12.** Representation of the first three harmonics  $y_1(t)$ .



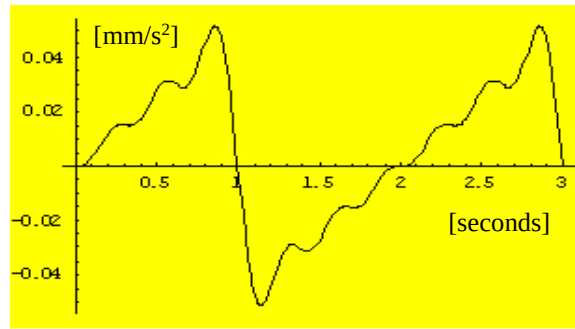
**Figure 13.** Representation of the first four harmonics  $y_1$ .



**Figure 14.** Representation of the first five harmonics  $y_1$ .



a) For 1 second.



b) For 3 seconds.

**Figure 15.** Representation of the first six harmonics  $y_1(t)$ .

#### 4. Conclusions

A high-level of computational security can be ensured by the use of several systems of computational mathematics, which we observe in this paper by comparing the graphs we obtained using two computational systems in the case of the dashboard system. Currently, research activities focus on the development of multidisciplinary experimental, theoretical and numerical skills put into play when designing structures, machine elements or, in general, mechanical systems. The aim of the research is to improve knowledge about the behaviour of materials and structures, to develop models and tools useful in the process of design of structures and machines and to capitalize on a technical culture in terms of analysis, design and manufacturing methodologies. This research is based on the fields of materials science, nonlinear mechanics of solids, fluids and coupled systems, acoustics, forming and processing techniques, experimental measurement methods and numerical modelling. The trend of

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