ESTIMATION OF PARAMETERS OF THE TORQUE CONVERTER OF AN AUTOMATIC TRANSMISSION OF A PASSENGER VEHICLE

Elias Dias Rossi Lopes[1], André Flora Alves Pinto[1] and Caio César do Prado Dorea Reis[1]

[1]Instituto Militar de Engenharia

E-mails: elias.rossi@gmail.com, andrefloraap@gmail.com, caiocdorea@gmail.com

ABSTRACT

The automatic transmission has been becoming more usual in the modern vehicles, even those considered low cost ones. The torque converter is the device responsible for the coupling between the engine and the gearbox in automatic transmission vehicles. In this context, this research aims the simulation and estimation of parameters of the automatic transmission of a passenger vehicle. In that purpose, it is implemented the Particle Swarm Optimization Method, which assists in obtaining parameters of the torque converter's curve from the engine full-load curve and the car real traction diagram. The torque converter's curves have fundamental importance, and only manufacturers have possession of that information. Beyond that, through those curves, it is possible: to raise the profit of the company, to develop an automobile that is economic in terms of fuel consumption and offers a better adaptation of the engine characteristic curve to the ideal traction curve.

INTRODUCTION

The methodology used in this article aims to obtain parameters of the characteristic curves of a TRILOK torque converter through the Particle Swarm Optimization (PSO) Method. To this end, this introductory section is subdivided into three subsections, in order to detail the process as a whole.

The first subsection details the operating principle of a TRILOK torque converter, as well as it presents its characteristics curves. At its end, the parametrization adopted for these curves and the parameters that the method seeks to estimate are specified.

In the second subsection, the matching process is approaches, which is the process of coupling between the full-load engine curve and the transmission system. The matching equating is presented and specifies as the process is performed for vehicle equipped with a torque converter. The matching process is also known as the direct problem and is used as the basis for formulating the inverse method.

Finally, in the last subsection, is presented the methodology of inverse problems in general. The concept of objective function is defined and the formulation adopted is presented. Focus is given to the stochastic method known as Particle Swarm Optimization, which is detailed and equated.

1. TORQUE CONVERTER

The basis of most of the types of automatic and semi-automatic transmissions used in vehicles engines is hydrodynamic coupling, so called because it operates with kinetic energy of the circulating fluid. This type of coupling involves a hydrodynamic clutch or a torque converter. Despite being similar in their constructions, the torque converter is capable of multiplying torque while the hydrodynamic clutch is not [1].

The hydrodynamic couplings use the inertia of the flow of a fluid. The individual components of a transmission of this type are the fluid flow devices. A rotatory pump plays the role of source of energy and the turbine of a primary engine. The mechanical energy applied through the transmission shaft is converted into hydraulic energy from the fluid and then back into the mechanical energy in the turbine, which is available (except losses) on the output shaft. The basic difference between a hydrodynamic clutch and a torque converter is that the torque has, in addition to the pump and turbine, a stator [2].

The advantages of a hydrodynamic clutch and a torque converter can be combined to avoid a decaying section in the efficiency curve of the torque converter. This type of device is known as a TRILOK torque converter and its simple construction and high level of efficiency make this converter suitable for vehicle transmissions and therefore are the only ones used in passenger cars. The torque converter operates in the first phase up to the lock-up point. In the second phase, the stator is released from the housing by a free wheel mechanism. As the stator rotates freely, there is no more torque conversion [2].

1.1. Characteristic Curves

A TRILOK torque converter has three main characteristic curves that depict its operation. The characteristic torque curve, which relates the torque conversion ratio (μ) and the speed conversion ratio (ν), the efficiency curve, which relates the efficiency coefficient (η) and the speed conversion ratio (ν), and the converter test curve, which relates the characteristic value (k) and the speed conversion ratio (ν) [2]. Of these special attention is given to the first and third (Figure 1(a)).

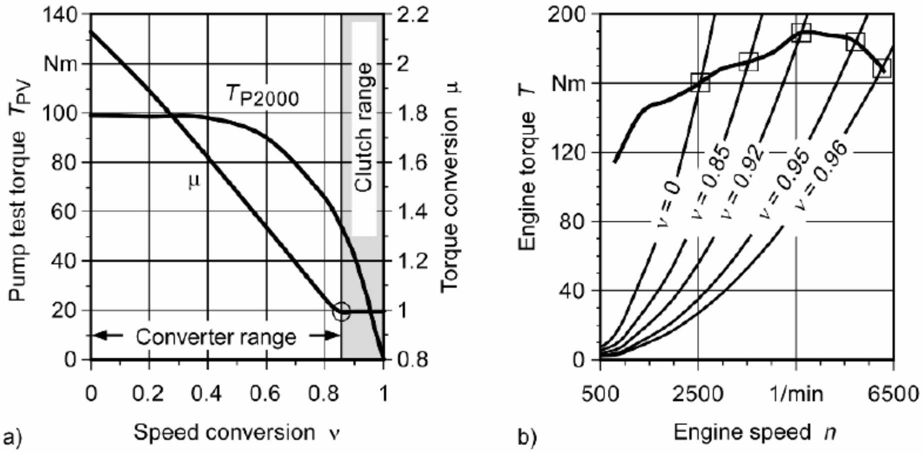

Figure 1: (a) TRILOK torque converter characteristic torque curve and test curve [2]. (b) Engine characteristic curve with the conversion parabolas [2].

Some characteristic point of the curves can be highlighted, such as, the stall point in which the speed conversion ratio is zero and the torque conversion ratio is maximum, and the lock-up point at which the converter starts operating as a hydrodynamic clutch assuming unitary torque conversion ratio.

The converter test curve is used to define the operating point in the engine characteristic curve in which the converter will act under certain torque and speed conversion ratios. The pump torque parabolas at an instantaneous conversion speed ratio (the so-called conversion parabolas) are added to the characteristic engine curve (Figure 1(b)) using the converter test curve and the Equation (1). These are the SPAN conversion parabolas covering a field of possible operational points [2].

$$k(\nu) = \frac{T_P}{n_P^2} \tag{1}$$

1.2. Parametrization

The application of the inverse problem methodology is performed with the purpose of obtaining the characteristic curves of a torque converter. In this direction, the characteristic and the test curves are parametrized with the help of a discrete set of parameters in order to represent them continuously and in the most faithful way possible.

In this motivation, the characteristic torque curve is described by a decreasing line in the region comprising speed conversion ratios between zero, in which the curve corresponds to a torque conversion ratio μ01, and ν02, in which the curve corresponds to a unitary torque conversion ratio. In the region comprising the speed conversion ratio between ν01 and one, a constant line describes the curve (Figure 2).

$$y = \mu_0 + \frac{(1 - \mu_0)}{\nu_{02}} x, \qquad 0 \leq x < \nu_{02} \tag{2}$$

$$y = 1, \qquad \nu_{02} \leq x \leq 1 \tag{3}$$

The values μ01 and ν02 are the parameters that define the characteristic curve of the torque converter, and physically represent, respectively, the torque conversion ratio of stagnation and the lock-up speed conversion ratio.

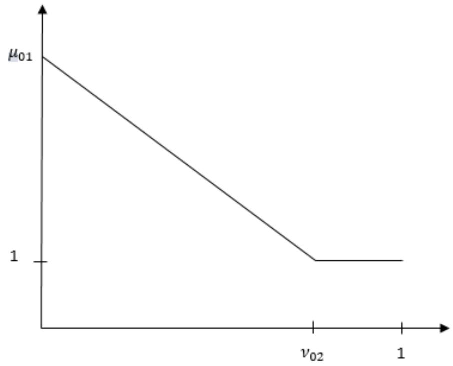

Figure 2: Torque converter characteristic torque curve parametrization model

The test curve is described by a constant line in the region that comprises speed conversion ratios between zero and ν_{01}, in which the curve corresponds a characteristic value of k_{01}. In the region comprising speed conversion ratios between ν_{03} and one, a decreasing line describe the curve, in which the curve presents a characteristic value of k_{min} 0 in speed conversion ratios of ν_{03} and one, respectively. Finally, in the region comprising speed conversion ratios between ν_{01} and ν_{03}, the curve is described by a fourth-order polynomial in which its coefficients are determined so conditions of continuity are respected (Figure 3).

$$p(\nu_{01}) = k_{01} \tag{4}$$

$$p(\nu_{03}) = k_{min} \tag{5}$$

$$\frac{dp}{d\nu}(\nu_{01}) = 0 \tag{6}$$

$$\frac{dp}{d\nu}(\nu_{03}) = -\frac{k_{min}}{1-\nu_{03}} \tag{7}$$

$$p(\nu_{02}) = k_{02} \tag{8}$$

The values k_{01}, k_{02}, ν_{01} and ν_{03} are the parameters that define the test curve of the torque converter.

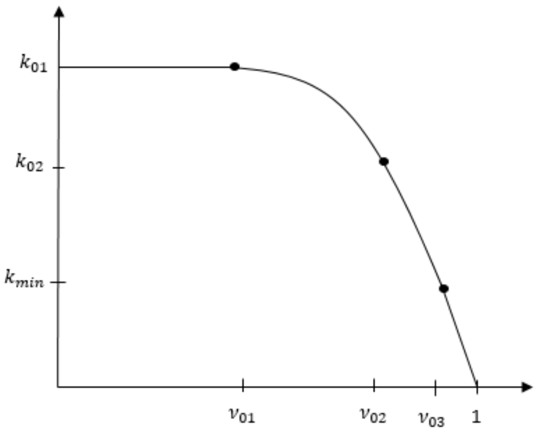

Figure 3: Test curve of the torque converter parametrization model.

1.3. Matching

Matching is the process of coupling the engine to the vehicle transmission. This is a problem in the field of vehicle longitudinal dynamics. The powertrain and its optimal conditions of work are acquired through computer simulations, bench and road tests. Vehicle transmissions are the connection between the engine and the drive wheels. The transmission adapts the power output to the power requirement of the car and to do that, it converts torque and rotational speed.

In this process of matching, the traction force available in the wheels and velocity of the vehicle can be calculated from the engine torque and speed, the dynamic radius of the tyre, the powertrain efficiency and the overall gear ratio, for a certain set of speed and torque conversion ratios. These calculations are equated by Equation (2) and Equation (3), respectively [2].

$$F_{Z,A} = \frac{\mu \cdot T(n_M) \cdot i_A}{r_{dyn}} \eta_{tot} \tag{9}$$

$$V = \frac{\nu \cdot n_M \cdot r_{dyn}}{i_A} \tag{10}$$

2. INVERSE PROBLEMS

Inverse problems are a field of study of applied mathematics that consists in discovering the causes from its consequences, in other words, to make the reverse process to obtain parameters or an inherent function of a system, from its behavior or its dynamics. Solutions of inverse problems involve stabilization techniques and are based on the reformulation of direct problems. The use of optimization techniques is not mandatory, but it is quite common to solve inverse problems.

Methods of solving inverse problems can be divided into stochastic and deterministic. Deterministic methods are computationally faster than stochastic, although they may converge to a local or non-global maximum or minimum, as desired. In addition, there are hybrid methods that combine the two so that the response can be achieved more quickly and appropriately, they can be combined as iterations progress within the program [3].

In order to solve inverse problems, optimization techniques must be used. Therefore the first step in solving inverse problems is the definition of the objective function. The objective function is the mathematical representation that is under evaluation and needs to be minimized or maximized. The relation between the objective function and its variables can be expressed through mathematical or physical models and in the impossibility, it is used the determination by experiments [3]. In this article the objective function used is the sum of the quadratic differences between the available traction calculated by the matching process and the withdrawal directly from the traction diagram, as equated in Equation (4).

$$f_{obj} = \sum (F_{Z,A} - F_{diag})^2 \tag{11}$$

2.1. Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) is a computational stochastic method that optimizes a problem through iterations by looking for a candidate solution of a measurable parameter. It solves the problem through a population of solution candidates and moving these particles into the search space. Each particle has its movement influenced by its best local position, but it also is guided by the best position of the entire population.

The method is based on the behavior of various species and attempts to balance the individual's individuality and sociability to locate the optimum point of interest. The iterative process can be represented by Equations (5) and (6), in which the left-hand term of the equality sign represents the particle in the iteration number k + 1, the first right-hand term represents the particle in the iteration number k, and the second, third and fourth terms represent the inertia, the individuality and the sociability, respectively [3].

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{12}$$

$$v_i^{k+1} = \alpha v_i^k + \beta_1 r_{1i}(p_i - x_i^k) + \beta_2 r_{2i}(p_g - x_i^k) \tag{13}$$

The entire methodology developed by this article of the application of the PSO to the matching problem in order to estimate parameters from the characteristic curves of a torque is summed up by the flow chart (Figure 4).

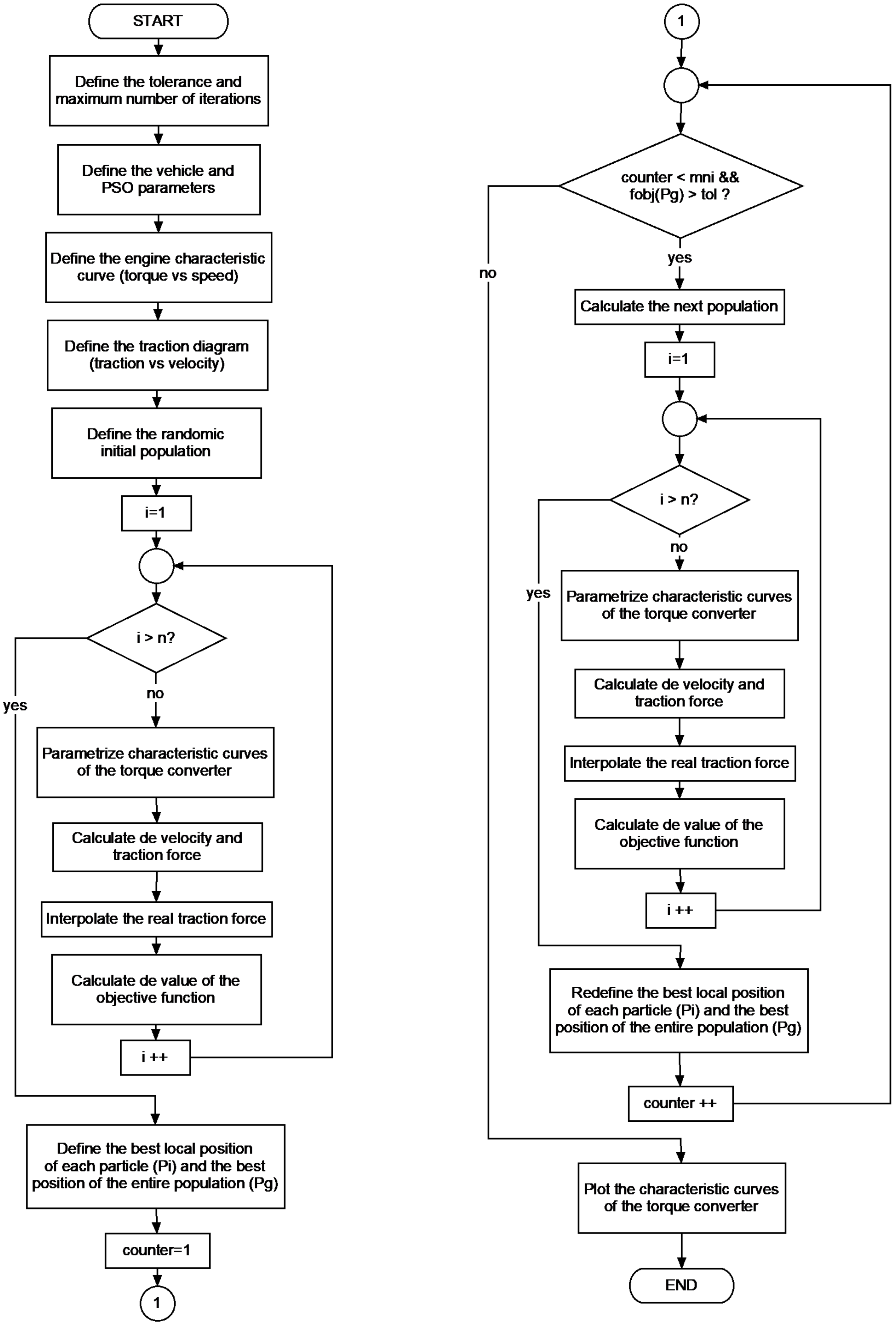

Figure 4: Flow chart summing up the methodology of application of the inverse problem's theory to a passenger vehicle equipped with a torque converter.

3. RESULTS

The results obtained in this article are exposed in the (Figure 5), (Figure 6) and (Figure 7). These results are obtained by the following data from a mid-size passenger car with a spark ignition engine, whose data, characteristic curves of the engine and torque converter, and traction diagram are shown in [2]. The methodology presented in previous sections is implemented with de help of the mathematical software MATLAB®.

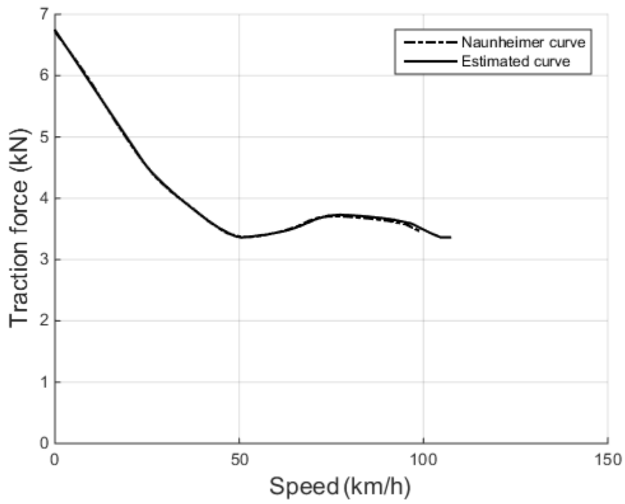

Figure 5: Second gear traction curves drawn from the traction diagram and estimated by the inverse method.

Figure 5 compares the second gear traction curves drawn from the traction diagram and obtained by the inverse method. Finally, Figure 6 and 7 contrast the characteristic and test curves, respectively, estimated and real.

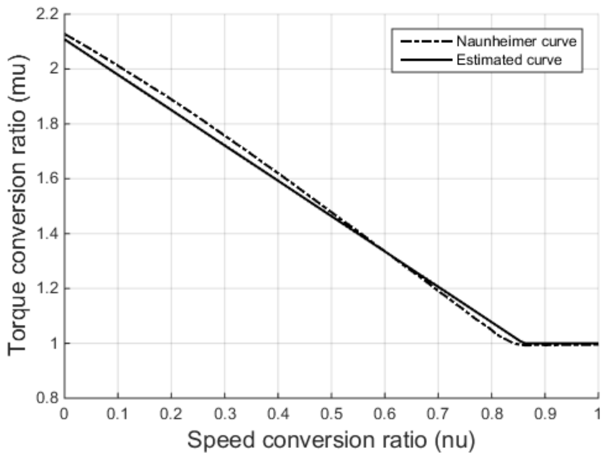

Figure 6: Characteristic curves of the torque converter drawn from [2] and estimated by the inverse method.

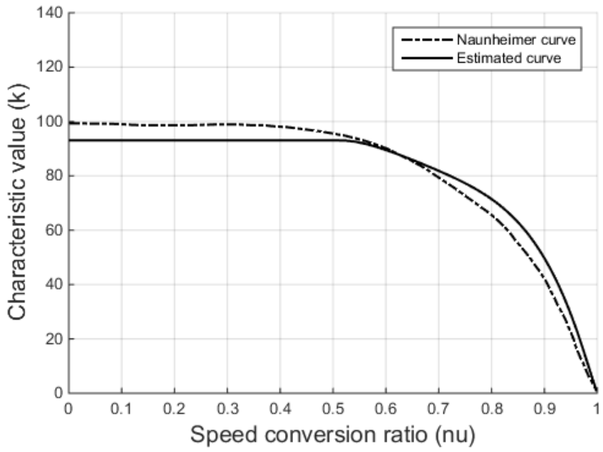

Figure 7: Test curves of the torque converter drawn from [2] and estimated by the inverse method.

3.1. Results Analysis

The values of the parameters estimated by the inverse method are shown in the (Table 1), in which they are compared with de ideal values It is concluded that the method converged in a general way and satisfactorily approached the real characteristic and test curves of the torque converter by means of a parametrization. The occasional divergences of the method and small approximation errors are mainly due to the problem having a high amount of local minimums besides minor parametrization failures. In this direction, to improve the method other types of objective function and parametrizations can be tested.

3.2. Sensitivity Analysis

Finally, a sensitivity analysis and study of possible errors that may influence the non-convergence of the method are performed. In the analysis, the graphs of the partial derivatives of the objective function are plotted as a function of each of the six parameters implemented (Figures 8-13). When such derivatives reach a null value it is indicated that the objective function reached a maximum or minimum point and such parameter has been optimized.

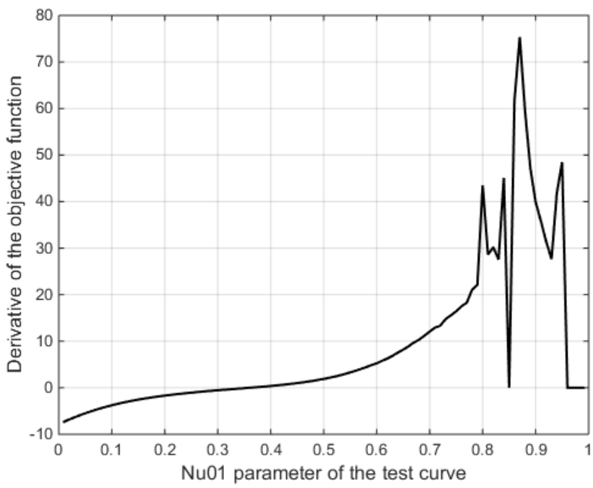

Figure 8: Partial derivative of the objective function in relation to the v01 parameter.

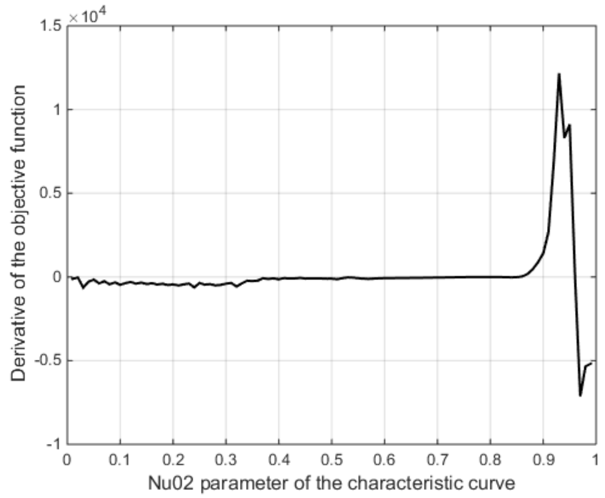

Figure 9: Partial derivative of the objective function in relation to the ν02 parameter.

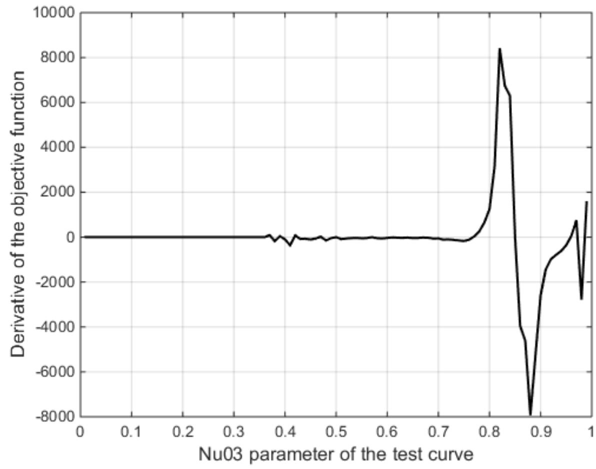

Figure 10: Partial derivative of the objective function in relation to the ν03 parameter.

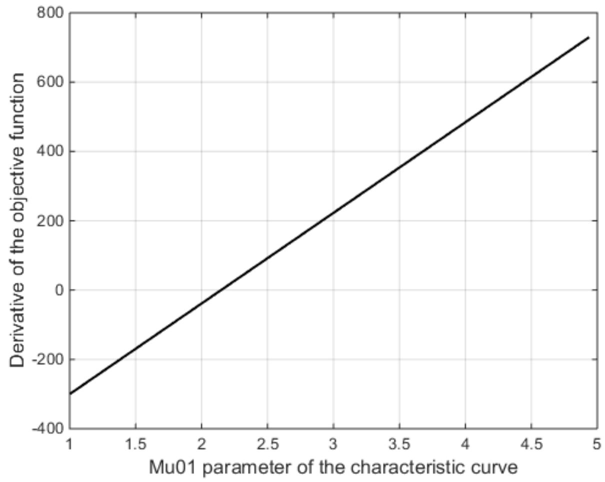

Figure 11: Partial derivative of the objective function in relation to the μ01 parameter.

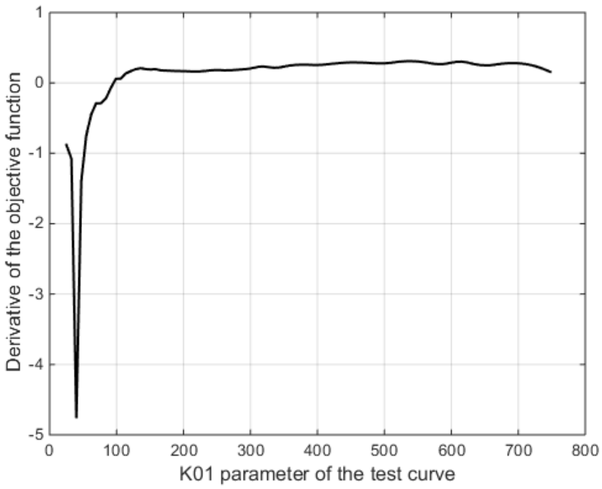

Figure 12: Partial derivative of the objective function in relation to the k01 parameter.

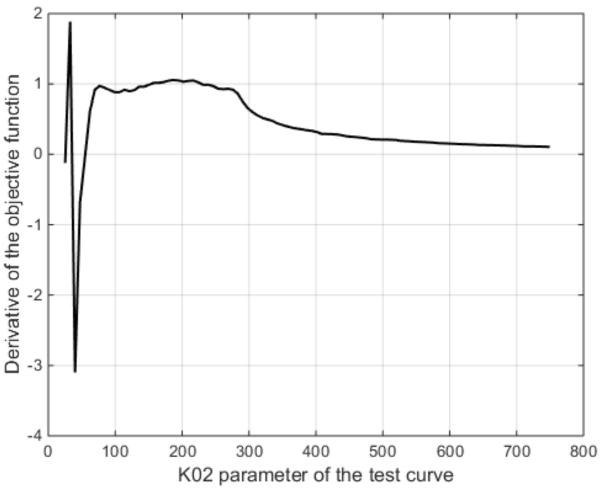

Figure 13: Partial derivative of the objective function in relation to the k02 parameter.

These graphs show that the sensitivity of the objective function to the parameters ν_{02} and ν_{03} are in the same order of magnitude, around 10,000, while the sensitivity of the objective function to μ_{01} parameter is in the order of magnitude of 1,000. The sensitivity to the ν_{01} parameter is in the order of magnitude of 100 and to the parameters k_{01} and k_{02} is in the order of 10. Such sensitivities are directly proportional to the degree of relative influence of the value of a parameter in relation to the value of the objective function. Therefore, as shown in Table 1 the most precise results are those related to parameters with higher level of sensitivity.

Table 1: Numeric results of the parameters estimated by the inverse method accompanied by ideal values.

Parameter	Estimated Value	Ideal Value
ν_{01}	0.51	0.40
ν_{02}	0.86	0.85
ν_{03}	0.97	0.96
μ_{01}	2.11	2.14
μ_{02}	93.1	99.3
μ_{03}	60.75	54.25

CONCLUSION

The objective of developing a reliable method for obtaining the characteristic curves of the torque converter of an automobile starting from the data of the characteristic curves of the engine and the transmission system is reached.

The proposed method allows to find the curves of the converter with acceptable accuracy. Note that there is an error in the curves, but that does not impact on the resulting traction curves. That is, although it is not a very accurate result, it guarantees an adequate vehicle performance analysis, which is the ultimate goal of the proposed methodology. This is because the error presented does not cause major changes in the motor torque, thus not affecting the available traction curve of the vehicle.

The method can still be incremented so that its inputs are actual vehicle performance data, such as maximum speed and acceleration, and not the traction curves, but this also requires changes in the optimization method used, as there are few estimated parameters for many data.

REFERENCES

[1] NUNNEY, Malcolm James. **Light and Heavy Vehicle Technology**. London: Routledge, 2007.
[2] NAUNHEIMER, Harald; BERTSCHE, Bernd; RYBORZ, Joachim; NOVAK, Wolfgang. **Automotive Transmissions: Fundamentals, Selection, Design and Application**. Springer Science & Business Media, 2010.
[3] COLAÇO, Marcelo J.; ORLANDE, Helcio R. B.; DULIKRAVICH, George S. Inverse and optimization problems in heat transfer. **Journal of the Brazilian Society of Mechanical Sciences and Engineering**, v. 28, n. 1, p. 1-24, 2006.