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LONGITUDINAL ACCELERATION OF A VEHICLE PROTOTYPE

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Abstract*. The present paper presents a proposal to improve the longitudinal performance of a land vehicle by adopting an unusual system of traction control. The system is able to improve the transfer of power from the motor to the ground and reduces the complexity of the task being executed by the driver. High-performance vehicles are able to achieve high levels of longitudinal acceleration and sometimes over-power leads to spinoff of the driving wheels, which reduces the ability of the tires to generate force and consequently acceleration of the vehicle.*
The proposed system acts beyond the control of the engine, through the derivation of the engine speed signal and its control in comparison with a predefined value. The control may delay or even suppress the ignition of the engine. Thus, the rate at which the engine generates speed and, consequently, the speed at which the vehicle accelerates, is limited. The benefits of the system are low cost and ease of application in a modern vehicle.

Keywords: Longitudinal performance, prototype vehicle, spark control

1. Introduction

This article deals with a proposal to improve longitudinal performance, the methodology developed was tested on a prototype vehicle. The object of study was applied to the Formula UFMG team vehicle, developed by engineering students from Universidade Federal de Minas Gerais for the Formula SAE Brazil competition. The purpose of this work is to design, build and test the spark cut technique.

An important principle of races is that the speed of the vehicle must never be constant unless it is limited by traffic conditions, safety or maximum speed of the vehicle. Therefore, we can conclude that the acceleration imposed on the vehicle must always be as large as possible, and any time the acceleration of the vehicle is zero should be minimized (eg gear changes). (Milliken et al. (1995))

The dynamic performance of the vehicle depends both on its mechanical characteristics (weight, power, quality of tires, etc.) and on the rider's ability to push him to the limit. So the integration of systems into the vehicle that helps the pilot to achieve greater assertiveness in their actions becomes an attractive option.

The prototype used for testing is powered by a 4-cylinder internal combustion engine of the Otto cycle and 599 cm3 displacement, controlled by a programmable electronic control unit, these characteristics make the engine capable of generating up to 70cv of power. Attached to it is a multi-plate clutch, oil-bathed, and a six-speed sequential gearbox manually operated. The total weight of the vehicle is approximately 300 kg. Because it is manual, the process of shifting gears depends a lot on the skill of the rider, which can lead to the occurrence of failures. This may imply an extended exchange time, so the proposal of this work is to use the spark cut techqnique, which is an auxiliary gear changing gear. Its use goes beyond reducing gear shifting time: it also makes the shift more assertive and simple, where only the selection lever movement is required.

Thus the objective of this work is to develop this system to improve the longitudinal performance of the vehicle and to assist the pilot in the driving of the vehicle.

2. Methodology

The methodology of this article will show the definitions of some concepts necessary for the understanding of the used system as well as its concept and application

2.1. Spark control

According to Braga (2007) the angle at which the spark occurs gives the name of the angle of ignition advance, being measured in relation to the PMS. The ignition advance should be adjusted so that the peak pressure is as large as possible and occurs at instants after the PMS. This ensures greater efficiency in the use of chemical fuel energy, as well as high torque on the motor shaft.

According to Gillespie (1992) in most MCIs, the increase of the ignition advance is directly linked to the increase of the rotation and reduction of the load, the set of these values being defined as the ignition advance map.

According to Pujatti (2007), the electronic control unit has the function of controlling the formation and ignition of the air-fuel mixture. It is a microcontrolled system that uses the signal coming from sensors as input to a series of mathematical algorithms that will determine the operation of the actuators.

The electronic control unit used is a programmable model, where the motor control parameters and their lines of code can be easily changed. Thus, it is possible to both calibrate the motor in operation and to program specific motor control modes.

2.2. Auxiliary systems for gear shifting

In the proposed system, the absence of torque is caused by suppression of the ignition at the time of exchange, where the electric circuit of the coils is opened, and the motor power cycle does not occur. Thus, the contact pressure between the exchange synchronizers ceases, making it possible to disengage the current gear. Due to the low inertia of the engine, its speed is reduced rapidly until the gear speed of the next gear is reached, thus ending the change. The system proposed in this work has electromechanical functioning, which is simplified and demands a lower cost of application when compared to electronic systems based on extensometry. In the prototype, the gear changes are carried out in a sequential manner by a lever which is connected to the drive of the gearbox by a push-pull cable. The mechanism is mounted in such a way that the lever, which lies in the cockpit of the vehicle on the left side of the steering wheel, is pulled backwards in the upshifts and pushed forward in the downshifts (Figure 1). The clutch drive is made by a manual lever, mounted directly on the selection lever. The sequence of the TR-04B shift gears is: 1-N-2-3-4-5-6.

Figure 1. a) Prototype cockpit b) Gear shift lever c) Shift lever shift lever with push pull

The proposed electromechanical system consists of a normally open switch and a normally closed relay. The key acts as the shift sensor and is positioned on the front face of the shift lever, so that when it is pulled back (upshift) the key has its state modified to closed, until the end of the operation exchange. Thus, the relay is started and the ignition of the motor is cut off by interrupting the coil supply circuit. The electrical diagram of the system is shown in Figure 2.

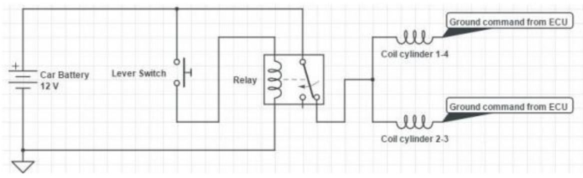

Figure 2. Electrical diagram of the system

In the downshifts, clutch engagement is required, and it is desirable for the engine to remain in its normal operating state. Therefore, the position of the key must be such that the activation of the clutch lever does not activate it. It was decided to use the key on the front face of the lever, excluding the contact point of the clutch lever when actuated. Thus, the operations of starting the vehicle movement and reducing gears are ensured, and have their normal operation.

2.3. System Features

According to Hansen (2013) the manual changes involve a sequence of events, in which the pilot must act as fast as he can. To reduce their influence in this process, gear shift assistance systems can be used, such as the application of actuators to the clutch drive and gearbox marker. Several studies have been carried out to apply exchange rates with semiautomatic exchanges in similar prototypes, but their application is complex and costly. These systems typically use pneumatic actuators controlled by electronic systems.

Another option to aid in gear shifting is the mechanism known as "shift without lift" or "spark cut". According to Costa (2001), test mechanisms are employed in sequential driving, such as that of sports bikes and competition vehicles of categories such as American CART and Formula SAE itself. According to Gillespie (1992) its operation is based on the momentary interruption of the power generation of the engine (ignition interruption, or spark cut), which allows that it is possible to work the gearbox without the operation of the clutch. Thus, the gear shift occurs "in time". Typically, an extensometer sensor is used on the gear shift lever, which has the function of informing the ECU of the moment of the change. In turn, the ECU cuts off the ignition of the engine for the required period until the end of the shift. The advantage of this system is that the process of manual upshift becomes faster by excluding the need to relieve the accelerator pedal and drive the clutch.

3. DIMENSIONING AND IMPLEMENTATION

In order for the system to function properly and be reliable, correct system design must be performed. This design is made for the switch and the relay, so that the mechanical and electrical loads (respectively) supported by them are adequate for the operation of the system and at the same time do not overload the components.

Distances of 0.2 and 0.4 mm were tested, promoted by electric isolated bases installed at the ends of the lever. After a few cycles of use the 0.2mm gap showed failure, keeping the key closed at all times. Thus, the distancing of 0.4mm was more adequate. The key was positioning a rubber at the end of the lever, and the whole set is isolated from the outside by an isolating tape. The top face of the lever has been kept isolated so that the clutch drive does not activate the system, thus breaking the vehicle and reducing gears as usual.

The first step was to measure the force required for the gear change with the help of a dynamometer (Figure 3). If a very low drive load is used, the gear shift time can be extended due to the early activation of the key. Otherwise, from a high load, the exchange would require a greater effort from the pilot, and could also overload the elements of the exchange.

Figura 3. Dinamômetro medindo a carga de acionamento da alavanca de troca de marcha

The measured load (12kg) was then inserted into a computational model capable of analyzing the deflection of the key, in which SolidWorks software was used (Figure 4). In this way, the width and thickness of the lever could be estimated so that the switching load of the exchange is capable of performing the desired deflection. The length of the key has been defined as the largest possible, allowing a larger contact area and making the prototype easier to drive. The final dimensions of the tube were 130 mm by 22.4 mm in diameter with wall thickness of 0.9 mm.

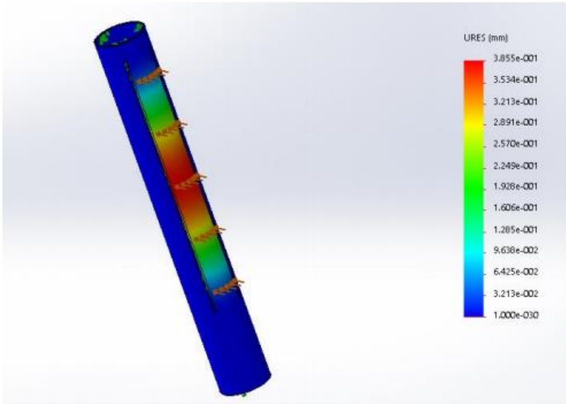

Figura 4. Simulated model in SolidWorks software

As established by the system, the relay used must have normally closed contact so that in the non-driven condition it allows normal coil operation. It must also be powered with 12 volts, which is the voltage used by the electric system of the vehicle, and finally, its triggered contact must withstand a current higher than the current of the coils, thus, the reliability of the system is ensured.

The spark cut acts on a critical component of the vehicle, which is the engine. After an analysis of its failure modes, it was concluded that the system can fail mainly in two ways: triggered locking and not triggered locking. Blocking would result in engine shutdown and consequent vehicle shutdown, which may cause the vehicle to lose time or even be disqualified from dynamic events. With not triggered locking, clutch-free gearshift and throttle relief are impossible. Thus, it was necessary to adopt mechanisms that circumvent the possible flaws, and that must be known by the pilot. Appendix I presents a Failure Mode and Effect Analysis (FMEA) chart of the spark cut and other systems applied to the vehicle, which is intended to inform pilots how to act in the event of systems failure to mitigate effects on the vehicle . In the event of a spark cut failure, a safety switch has been adopted which deactivates it, where its contact acts in parallel with the relay contact. In this way, panel switch actuation powers the coils, regardless of the relay status (open, closed or absent). This makes the shifting of gears back to purely manual, negative effect that is justified by the benefit of keeping the engine still running. Figure 5 shows the final electrical circuit of the system. The safety key has been mounted on the dashboard of the vehicle, and the system harness is integrated with that of the vehicle.

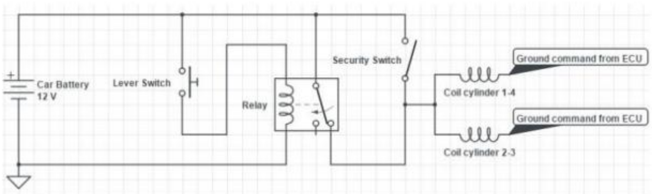

Figure 5. Electrical system final circuit with safety key

4. VALIDATION

The proposed system underwent several stages of development and testing. In its final version, it was analyzed in a subjective and objective way. Subjective tests were performed with the vehicle on the track, where the pilot's evaluation indicated the system's capacity for assistance and it was possible to evaluate the feasibility of its use. The objective tests were performed in the laboratory in order to analyze the influence of the systems on the performance of the vehicle. On both occasions, the duration of specific events was measured by video recording using a high-frequency image capture camera (GoPro Hero 3 filming at 120fps - frames per second) and its subsequent analysis in video editing software (Sony Vegas Pro 12), where it was possible to measure the time by the number of frames elapsed. It is important to note that this method of time measurement has a sensitivity of 8.33 milliseconds (1 / 120s), which is the elapsed time between two consecutive frames of the video.

The spark cut system was analyzed by measuring the gear shift time, with and without the use of the mechanism. The test was performed in the workshop and with the vehicle stopped on trestles. It is important to emphasize that this method of analysis is capable of evaluating the influence of the system in the process of gear change, and its result can be extended to the condition of the vehicle in movement, since the movements necessary for the exchange are the same.

5. Conclusion

In this section, the results regarding the performance of the proposed systems will be presented and discussed. The different constructive parameters employed will be analyzed, as well as the strategies of electronic controls.

The spark-cut system went through several stages of development, where the main components (drive switch and relay) underwent several modifications. The final proposal, which was implemented in the prototype, proved to be a reliable and satisfactory system. The subjective analysis of the system indicates that it presents a gain to the driving of the vehicle, because in fact it makes the ascending gear changes simpler, where only the movement of the lever is necessary. Thus, the process of shifting is less dependent on the skill of the rider, which leads to greater assertiveness in its execution and better performance of the vehicle. In the objective analysis, ten measurements of the gear change time were performed for each case, with and without the spark cut, and the values found are shown in Table 1 and Table 2, respectively. The result of the analysis indicates that the process of gear change with the use of the system presents an average time of 253.3 milliseconds, with standard deviation of 40.3 milliseconds, while the average time of change of gear in the conventional way was of 470 milliseconds, with a standard deviation of 114.9 milliseconds.

Tabel 1. Gear shifting time, measured with the spark-cut technique

Tempo	Troca 1	Troca 2	Troca 3	Troca 4	Troca 5	Troca 6	Troca 7	Troca 8	Troca 9	Troca 10
Início (quadro)	327	362	394	428	454	511	538	567	595	625
Fim (quadro)	358	382	419	461	486	543	566	599	630	661
Total (quadros)	31	20	25	33	32	32	28	32	35	36
Total (ms)	258,3	166,7	208,3	275,0	266,7	266,7	233,3	266,7	291,7	300,0
Tempo Médio (ms)	253,3									
Desvio Padrão (ms)	40,3									

Tabela 2. Gear shifting time, measured without the spark-cut technique

Tempo	Troca 1	Troca 2	Troca 3	Troca 4	Troca 5	Troca 6	Troca 7	Troca 8	Troca 9	Troca 10
ínicio de alívio do pedal (quadro)	499	536	571	606	623	693	743	818	872	915
Ínicio de ac. da alavanca (quadro)	515	564	587	618	655	721	707	834	888	919
Fim de acion. da alavanca (quadro)	539	588	615	650	691	757	787	866	928	963
Fim de alívio do pedal (quadro)	543	580	611	646	667	757	795	870	928	967
Tempo total de troca (quadros)	44	52	44	44	68	64	88	52	56	52
Tempo total de alavanca (quadros)	24	24	28	32	36	36	80	32	40	44
Tempo total de troca (ms)	366,7	433,3	366,7	366,7	566,7	533,3	733,3	433,3	466,7	433,3
Tempo total de alavanca (ms)	200,0	200,0	233,3	266,7	300,0	300,0	666,7	266,7	333,3	366,7
Ocorrência de sobregiro										
Ocorrência de acel. prematura										
Tempo médio de troca (ms)	470,0	Desvio	114,9							
Tempo médio de alavanca (ms)	313,3	Desvio	135,4							

Table 2 also shows the periods of activation of the shift lever and the accelerator pedal, and it can be seen that in 50% of the cases there was some minor fault in the exchange process: activation of the previous clutch to the accelerator start of the shift or throttle drive prior to the clutch coupling (at the end of the process). Both failures induce over-rotation of the engine when uncoupled, which leads to increased fuel consumption and wear of the clutch at the time of coupling. The average switching time of the shift lever in conventional mode, 313.3 milliseconds, was similar to the time with spark cut (253.3 ms), and it can be concluded that the difference in the total gear change time between the two is in fact the reduction of the total complexity of the process. Thus, it can be concluded from the measurements that in addition to the reduction of 46% of the mean time of exchange with the spark cut (253.3 ms versus 470 ms of the manual exchanges) the mechanism still shows a smaller influence of the pilot's ability during the exchange rate, which is indicated mainly by the smaller standard deviation of the measured exchange times (42.2 ms versus 114.9 ms). Thus, the Spark Cut system proved to be a good implement to the vehicle, having achieved its goal of reducing the exchange time and helping pilot in its task.

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7. Responsibility notice

The authors are the only responsible for the printed material included in this paper.

Apendix I –FMEA table

FMEA - Failure Mode and Effect Analysis

Para esta análise do modo e efeito de falha, foram consideradas apenas as falhas em pista, onde o piloto deverá realizar as ações corretivas.

Descrição do Produto/ Processo	Funções do Produto	Tipo de Falha Potencial	Efeito de Falha Potencial	Causa da Falha em Potencial	Controles Atuais	Índices				Ações Recomendadas de Melhoria
						S	O	D	R	
Corte de Centelha	Auxiliar a troca de marchas	Travamento em posição Ativada	Perda de potência, pois a ignição cessa Pode culminar no desligamento do motor	Curto-circuito no aterramento do relé	Desativamento do sistema via chave no painel e repartida do motor caso necessário Trocas de marchas voltam a ser manuais	8	1	8	7	Recheck do circuito
Corte de Centelha	Auxiliar a troca de marchas	Travamento em posição Ativada	Perda de potência, pois a ignição cessa Pode culminar no desligamento do motor	Travamento do relé ligado	Desativamento do sistema via chave no painel e repartida do motor caso necessário Trocas de marchas voltam a ser manuais	8	1	8	7	Utilização de relés confiáveis
Corte de Centelha	Auxiliar a troca de marchas	Travamento em posição Ativada	Perda de potência, pois a ignição cessa Pode culminar no desligamento do motor	Travamento da chave da alavanca fechada	Desativamento do sistema via chave no painel e repartida do motor caso necessário	8	6	8	7	Dimensionamento
Corte de Centelha	Auxiliar a troca de marchas	Travamento em posição Desativada	Não é possível realizar a troca sem embreagem ou diminuição no acelerador	Falha no circuito, fio cortado	Desativamento do sistema via chave no painel e repartida do motor caso necessário	6	2	7	4	Recheck do circuito
Corte de Centelha	Auxiliar a troca de marchas	Travamento em posição Desativada	Não é possível realizar a troca sem embreagem ou diminuição no acelerador	Falha no relé, travamento aberto	Desativamento do sistema via chave no painel e repartida do motor caso necessário	6	1	7	4	Utilização de relés confiáveis
Corte de Centelha	Auxiliar a troca de marchas	Travamento em posição Desativada	Não é possível realizar a troca sem embreagem ou diminuição no acelerador	Falha na chave da alavanca, travamento aberta ou corrosão dos contatos	Desativamento do sistema via chave no painel e repartida do motor caso necessário	6	4	7	4	Dimensionamento
Controle de Tração	Manter o veículo em sua maior aceleração	Não atuação - ocorrência de escorregamento	Excesso de deslizamento do pneu em condição de aceleração a plena carga	Escolha de parâmetro MaxRPM muito grande	Abaixar parâmetro MaxRPM	3	4	7	3	Utilização de simulações para escolha de parâmetros
Controle de Tração	Manter o veículo em sua maior aceleração	Sobre-atuação - baixo desempenho de	Baixo desempenho de aceleração a plena carga	Escolha de parâmetro MaxRPM muito pequeno	Aumentar parâmetro MaxRPM	8	4	3	8	Utilização de simulações para escolha de parâmetros
Controle de Tração	Manter o veículo em sua maior aceleração	Ação de controle com resultado irregular	Desempenho do veículo/Aceleração irregular a plena carga	Escolha de parâmetro proporcional muito grande	Diminuição de parâmetro proporcional	6	4	9	6	Utilização de simulações para escolha de parâmetros
Controle de largada	Manter a rotação desejada no momento de largada	Rotação Configurada alta demais	Excesso de deslizamento do pneu	Escolha de parâmetro launchRPM muito grande	Abaixar parâmetro LaunchRPM	3	4	5	2	Utilização de simulações para escolha de parâmetros
Controle de largada	Manter a rotação desejada no momento de largada	Rotação Configurada baixa demais	Baixo desempenho de aceleração, e possível desligamento do motor	Escolha de parâmetro launchRPM muito pequeno	Aumentar parâmetro LaunchRPM	8	4	8	7	Utilização de simulações para escolha de parâmetros
Controle de largada	Manter a rotação desejada no momento de largada	Não entrada no modo de largada	Rotação de largada mais alta que a esperada	Falha de reconhecimento das condições: tps, velocidade	Desativação do sistema via chave no painel Desativação do sistema via interface da central	4	2	9	3	Check dos sensores
Controle de largada	Manter a rotação desejada no momento de largada	Não saída do modo de largada	Rotação limitada à LaunchRPM após o início do movimento	Falha de reconhecimento de velocidade	Desativação do sistema via chave no painel Desativação do sistema via interface da central	9	2	9	9	Check dos sensores
Medição de velocidade	Medir a velocidade e informar a central eletrônica	Não leitura da velocidade	Central não reconhece velocidade, logo os sistemas dependentes não funcionam	Falha no circuito, fio cortado	Desativar sistema de leitura de velocidade	5	3	4	2	Check do circuito
Medição de velocidade	Medir a velocidade e informar a central eletrônica	Não leitura da velocidade	Central não reconhece velocidade, logo os sistemas dependentes não funcionam	Falha no sensor	Desativar sistema de leitura de velocidade	5	2	4	2	Check da luz do sensor, e escolha de sensores confiáveis
Medição de velocidade	Medir a velocidade e informar a central eletrônica	Não leitura da velocidade	Central não reconhece velocidade, logo os sistemas dependentes não funcionam	Falha no condicionador de sinais	Desativar sistema de leitura de velocidade	5	2	4	2	Check da luz do circuito
Medição de velocidade	Medir a velocidade e informar a central eletrônica	Leitura incorreta da velocidade	Central lê velocidade incorreta, podendo apresentar falhas nos sistemas relacionados e nos dados de log	Falha no sensor/posicionamento	Desativar sistema de leitura de velocidade	5	4	4	2	Check da posição do sensor, aplicação de adesivos na montagem
Medição de velocidade	Medir a velocidade e informar a central eletrônica	Leitura incorreta da velocidade	Central lê velocidade incorreta, podendo apresentar falhas nos sistemas relacionados e nos dados de log	Falha no condicionamento de sinais	Desativar sistema de leitura de velocidade	5	1	4	2	Check da calibração do sistema de condicionamento