PROCESS MODELING FOR A ROCKET MOTOR TESTING

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Abstract. *The purpose of this paper is to present a process modeling for rocket motor testing as a preliminary approach using EPC notation. The rocket testing process is not a repetitive process even if the same rocket motor is used. Considerations about sensors, environment conditions and budget are restrictions to repeat the same test. The process modeling is useful to understand the interfaces among test planning teams and among the test activities themselves. Each one of the activities of the process can be detailed with its all respective tasks and a sample of this is presented. The rocket motor testing process is modeled and three troubles are presented and then, in a retrospective way, the adequacy of the model as a training aid is discussed.*

Keywords: *process, modeling, testing, rocket*

1. INTRODUCTION

A rocket can be constituted of one or more propeller stages, depending on the necessary energy to reach the distance from Earth to the specified mission's target. The rocket motor is the main component of a propeller stage. One of characteristics of a Solid Rocket Motor (SRM) is that once started the burning it cannot be controlled or interrupted without destructing the rocket stage. The knowledge about the propulsive characteristics of the propellant is very important to refine the trajectography calculus up to the allowed uncertainty of the rocket mission. These characteristics are obtained by firing testing in test benches: the SRM firings tests, especially those with mass propellant bigger than 1,000 kg, involve several expert teams, different resources and special logistics. As a result, these tests are complex and potentially dangerous. Due to its multidisciplinary characteristic, these testing are not under responsibility of a specific sector, but rather, they are viewed and dealt with like as Integration and Testing Division's project. For this reason, manager is designed for each test, and he (she) answers directly to the Division's chief. The manager - named Testing Coordinator - is the responsible for managing all processes, from the client request reception to the report sending. The coordinator's job is set the teams up from different laboratories (Fig. 1) and to gather the necessary people from transportation, security, safety, test site maintainers, public relations, among others.

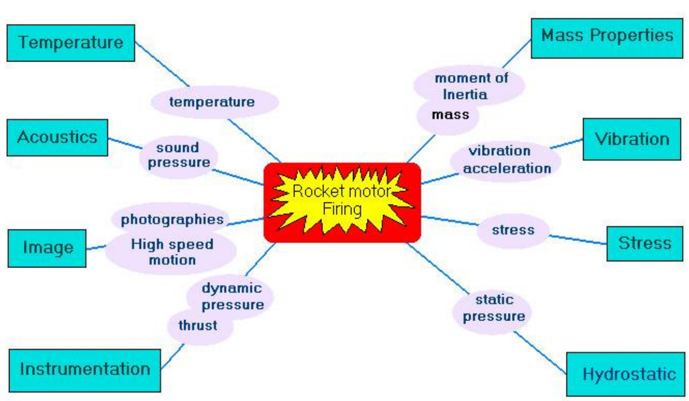


Figure 1 – Laboratories and their measurements during SRM firing.

A number of such tests have being already successfully executed by experienced professionals. Nevertheless, the tests are managed in an *ad hoc* way; consequently the process management experiences as well as the lessons learned aren't formally incorporated to the organization knowledge to be re-used further on, especially when new coordinators are called in. The Integration and Testing Division (ITD) just have begun a training program for new coordinators for these especial tests. Naturally, procedures, methods or tools for modeling the testing process are welcome as they could be useful for both training and process optimization.

This work presents a preliminary version of a SRM testing process modeling that uses the *Event-driven Process Chain (EPC)* as the modeling tool. The SRM firing testing process is modeled and then, in a retrospective way, the adequacy of the model as a training aid for the new test coordinators is analyzed.

2. BACKGROUND

EPC (Hunt, 1996) is a notation that represents a chain of events and functions, where each event provokes a function, followed by another event, as a result of the former action. The relationship among events and functions is established by logic connectors and arcs as pictured in Fig.2.

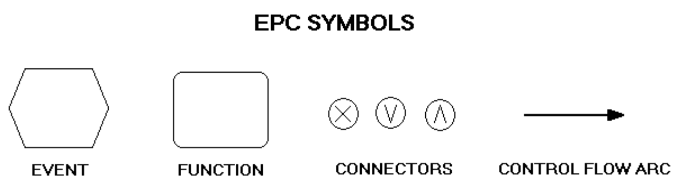


Figure 2 – EPC symbols (Van der Aalst, 1999; Mendling e Nüttgens, 2003)

According Mendling and Nüttgens (2003, p.131), "the major advantage of EPCs is their ability to express processes in an intuitive way". The EPC representation might show the process in several levels of detailing, starting up from lumped activities to very fine activity details. Figure 3 shows the EPC first level description of the SRM testing process.

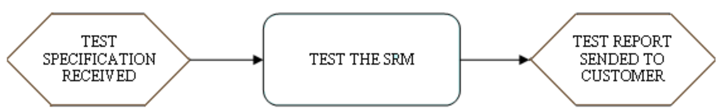


Figure 3 – EPC first level description of the Rocket Motor Testing Process

A SRM test consists of a working test of a rocket motor with solid propellant. The propellant is a composite of combustible and oxidant that react in presence of heat, provoking the expulsion of the gas and the consequent reaction of the impulse on the contrary direction. The main objective is to determinate the propulsive characteristics of the motor, although the test are frequently used for other purposes as, for example, thermal environment studies, vibration and acoustics environment studies and so on. For some tests, the motor is also used like high pressure acoustic source for research of isolation materials. Figure 4 depicts a rocket motor installed in a test bench.

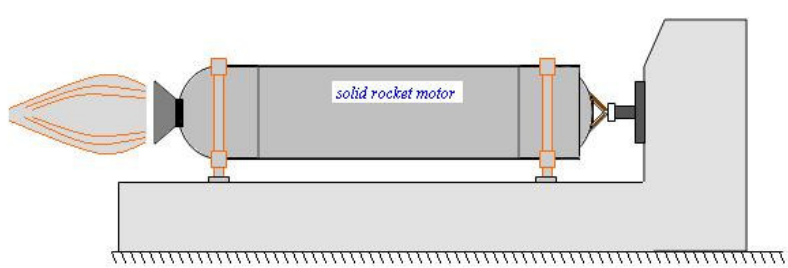


FIGURA 4 – A solid rocket motor firing testing.

3. THE SRM TESTING DESCRIPTION

The following SRM test description is based on Carmona (2006) and Oliveira (2006) reports. It is constituted by a set of 80 major activities summarized shown in Tab. 1.

Table 1. SRM testing activities summarized.

Activity		From	To	Resources
1	Request for support	Test coordinator	Laboratories and sections	Written memo
2	Reactivate the firing test	Test Bench Lab	Support sections	Written memo
3	Measure components mass properties	Mass Properties Lab	Test coordinator	Written memo
4	Prepare SRM for sensors	Integration Lab	Test coordinator	Test chronogram
5	Check instruments	Labs teams	-	Procedures
6	Carry instruments to test bench facilities	Transport section	Test coordinator	Telephone call
7	Integrate SRM	Integration Lab	Test coordinator	Test chronogram
8	Install SRM in test bench	Test Bench Lab	Test coordinator	Test chronogram
9	Install and test sensors	Labs teams	Test coordinator	Test chronogram
10	Do the general test	Labs teams	Test coordinator	Test chronogram
11	Do the firing test	Test Bench Lab	Test coordinator	
12	Validate results	Labs teams	Test coordinator	
13	Sand results and comments	Labs teams	Test coordinator	
14	Consolidate all information	Test coordinator	ITD chief	
15	Deliver the test report	ITD chief	Client	

Comments:
Activity 2: The low cadence of tests imposes the reactivation of the big test benches and test facilities each time. To this end, the following tasks are carried out: lifting tackle cleaning and lubrication; overhead traveling crane maintenance; check lamps, electric sockets, wiring and power source; mechanical interfaces cleaning, and so on.
Activity 3: The SRM main components are the rocket motor cylinder, the carter, the divergent and the igniter.
Activity 10: This test checks interferences between the measurement chains.
Activity 11: If the general test is well finished, the firing test is done, with all required safety condition. In case of failure or interferences, the test is repeated after the problem correction.
Activity 12: The teams validate their results by post calibration, historical data comparison or data simulation.
Activity 13: All the results and comments about reliability and integrity of data are sanded to coordinator.
Activity 14: The coordinator consolidates all information received in a unique report with his own comments. Your responsibility only ends after approval of the ITD chief.
The safety activities were not considered to this work.

3. THE *EPC* MODELING FOR THE SRM TESTING

The modeling of events and functions of the testing process is recorded using the EPC notation. Only a small part of model is shown in Fig. 5 due to confidentiality restrictions.

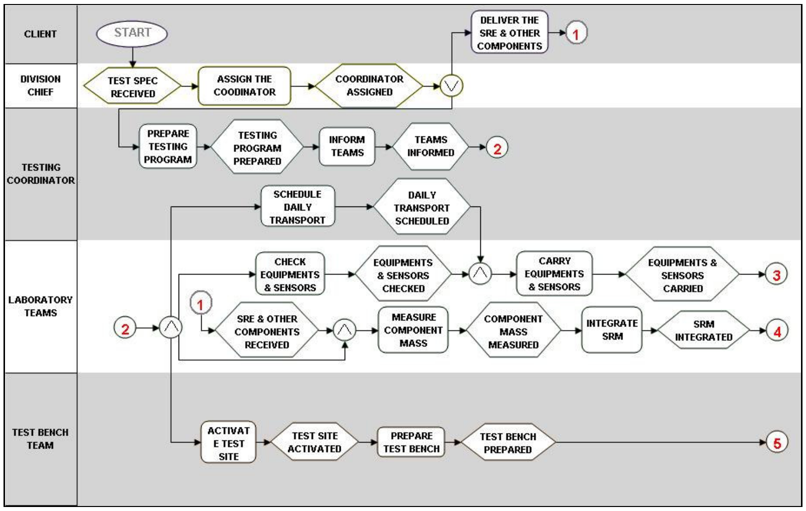


Figure 5A – EPC of the SRM firing test process.

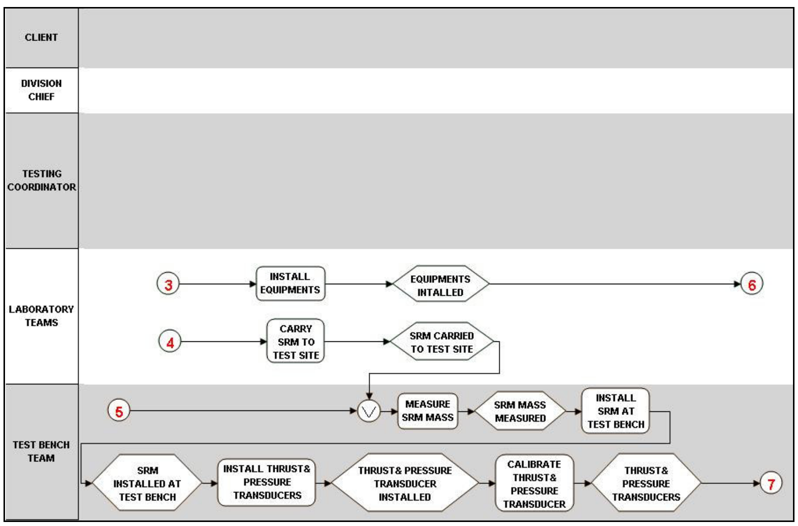


Figure 5B – EPC of the SRM firing test process.

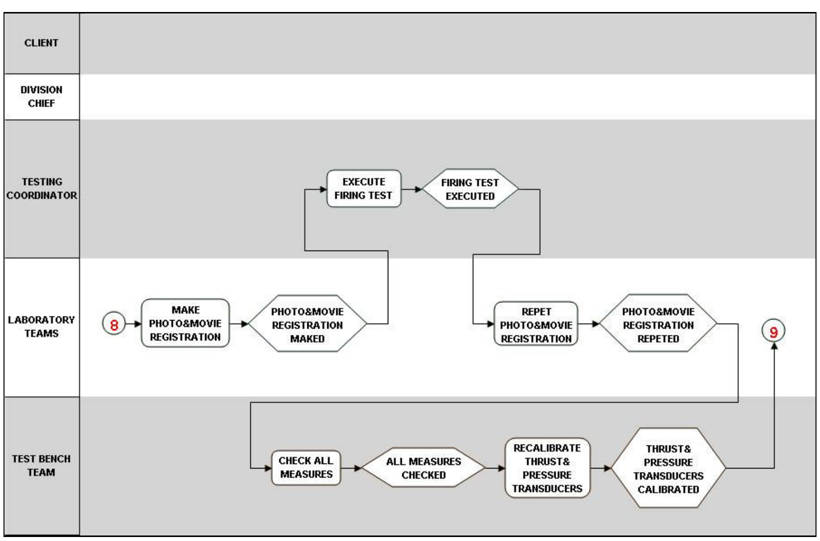


Figure 5C – EPC of the SRM firing test process.

4. RESULTS

Each one of the activities (functions) of the process can be further detailed with all its respective tasks. A sample of this detailing is presented by the activity MEASURE SRM MASS (see Tab. 2).

Table 2. Measure SRM mass activity detailed.

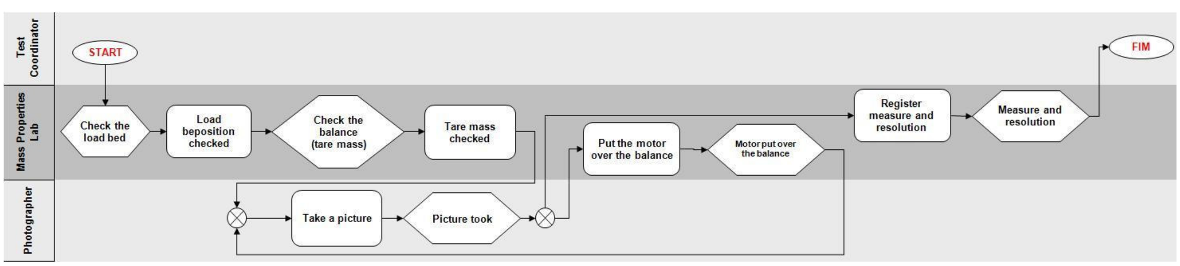
Activity		From	To	Resources
1.	Check the load bed positioning on the scale;	Mass Properties Lab technical personnel	Test Coordinator	Lab procedure
2.	Check the balance indicator (tare mass);	Mass Properties Lab technical personnel	Test Coordinator	Scale manual
3.	Take a picture of the load bed and the balance;	Photographer	Mass Properties Lab	-
4.	Put the motor over the balance using lifting belt and accessories;	Mass Properties Lab technical personnel	Test Coordinator	Mass measurement procedure
5.	Take a picture of measurement configuration;	Photographer	Mass Properties Lab	-
6.	Register the measure and the balance resolution;	Mass Properties Lab technical personnel	Test Coordinator	-

Comments:

According previous study (Carmona, 2006), the mass measurement was done without any concerns about the same configurations of measurement, even to rockets from the same family. This activity was executed among the integration activities of the rocket just by convenience of chronogram and nearest balance.

The EPC of the measure SRM mass activity is shown in Fig. 6 above.

Figure 6 – EPC of the measure SRM mass activity.



5. DISCUSSION

The EPC notation has allowed a better understanding of the testing process traditionally used by the more experienced coordinators. The visibility of the sequence of tasks and a clear definition of the interfaces shown through the sketched model has avoided troubles occurred in the others tests. Three of them are described below.

In the past, if the hydrostatic test of the motor tube had a delay, the mass measurement of the configuration 1 or 2 (Table 3) would be cancelled. In this case, the liner efficiency like thermal protection couldn't be evaluated properly.

Table 3 – Mass measurement configuration

Measurement Configuration	Component	Mass Measurement	
		Before test	After test
1	Motor tube empty	X	
2	Motor tube with liner	X	
3	Motor tube with propellant	X	

4	front cover	X	X
5	nozzle	X	X
6	rocket motor without front cover and nozzle	X	X
7	complete rocket motor	X	X

Another trouble was the changes of the order of execution of the planned activities. This had provoked the cancelling of some mass measurement configuration. With the use of the EPC, the repetition of the configuration of mass measurement to each new test is forced by the chaining of the activities, becoming more difficult its execution out of the planed sequence. This repetition depended on the chronogram conveniences, with impact over the measurement uncertainty or over the thermal efficiency of the liner. In other words, if the rocket motor (measurement configuration 6) was available to measurement between two activities on a certain moment, the mass measurement is done using a nearest scale, without concerning about the scale´s uncertainty, just to optimizer the time schedule.

The EPC also allowed better rationalization of the work by incorporating the experience of some coordinators in the model of the process of SRM testing. Its use to the next tests will allow better evaluation of others benefits.

The model establishes the most convenient sequence, besides that it shows clearly to the client what would be the impact over the subsequent events if all the components are not received.

The third problem avoided by modeling is the changing of responsible during critical function, once the *EPC line* notation permits to define clearly who is responsible for each event and function. It's enough to construct a model until the level of the person in charge.

6. CONCLUSION

This paper has presented a preliminary approach of a process modeling for a rocket motor testing using Event-driven Process Chain notation. Currently, although at initial stage, it can be envisaged that the EPC model is a useful tool to be used by test coordinators, to establish more formally the experience to manage complex testing. Next step is to deploy the functions in a lower level EPC model, and validate this approach against new SRM testing.

7. ACKNOWLEDGEMENTS

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9. RESPONSIBILITY NOTICE

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