DYNAMIC SIMULATION OF VEGA SRM BENCH FIRING BY USING PROPELLANT COMPLEX CHARACTERIZATION

MSC Software
University Roadshow
La Sapienza, Rome 12 June 2012
VEGA is the small European launcher developed by ESA. The qualification maiden flight has been successfully performed on February 13th 2012 from the Kourou Space Center.

4 stages:

3 solid rocket stages

+ Liquid rocket upper module (AVUM)

During the VEGA’s launcher development from 2004 up to now, several firing test have been performed.
INTRODUCTION

**VEGA** is the small European launcher developed by ESA. The qualification maiden flight has been successfully performed on February 13th 2012 from the Kourou Space Center.

4 stages:

- 3 solid rocket stages
- Liquid rocket upper module (AVUM)

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INTRODUCTION

Firing test

P80 FIRING TEST (Kourou)

Z23 FIRING TEST (Sardinia)

Z9 FIRING TEST (Sardinia)

OBJECTIVE: SRMs qualification and characterization

Dynamic characterization → Prediction and simulation of the VEGA launch dynamic environment for Sub-structures and PayLoad.

Solid propellant is around 90% of the SRM mass

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AGENDA

1. EXPERIMENTAL CHARACTERIZATION OF THE VIBRATION-DAMPING PROPERTIES OF SOLID PROPELLANT
   1.1 Standard test method
   1.2 Resonance test method
   1.3 Dynamic mechanical analyzer test method

2. SOLID PROPELANT COMPLEX DYNAMIC MODULUS INTRODUCTION IN VEGA SRMs FEM

3. EFFECT OF THE INTRODUCTION OF THE COMPLEX DYNAMIC MODULUS OF ELASTICITY IN THE ZEFIROS FIRING TEST NUMERICAL SIMULATIONS

4. CONCLUSIONS AND FUTURE DEVELOPMENT
OBJECTIVE: characterize dynamic modulus $E^*$ as function of frequency

$$E^* = E'(1 + i\eta)$$

where:

- $\eta$ : Loss modulus
- $E'$ : Storage modulus

Standard Procedure $\rightarrow$ ASTM standard E 756-05


Dynamic Mechanical Analyzer (DMA) Procedure

Identify the best experimental procedure applicable to the solid propellant:
- Results applicability
- Technological aspects
- Cost

Procedures applied on VEGA INERT PROPELLENT
EXPERIMENTAL CHARACTERIZATION OF THE VIBRATION-DAMPING PROPERTIES OF SOLID PROPELLANT

STANDARD TEST METHOD

**APPARATUS:**
- rigid test fixture to hold the test specimen
- environmental chamber
- vibration transducers
- shaker

**METHOD:**
The ratio of response to force presented as a function of frequency must then be used for evaluating the material characteristics. Indirect measurement using damped cantilever beam theory.
Linear range: damping materials behave in accordance with linear visco-elastic theory.

Specimen configuration

Samples dimensioned in order to have a set suitable to cover a wide frequency range.

Test performed at 23 C

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EXPERIMENTAL CHARACTERIZATION OF THE VIBRATION-DAMPING PROPERTIES OF SOLID PROPELLANT

RESONANCE PROCEDURE

APPARATUS:
- rigid test fixture to hold the test specimen
- environmental chamber
- vibration transducers
- shaker

METHOD:
Once the resonant frequency is established, the required measurements of shaker acceleration, specimen acceleration, temperature and frequency are made and the complex Young's modulus can be calculated applying data reduction equation.

Samples dimensioned in order to have a set suitable to cover a wide frequency range.

Test performed at 23 C
Dynamic Mechanical Analyzer (DMA) Procedure

**APPARATUS:**
- DMA

**METHOD:**
To check in frequency and phase the deformation trend induced on the sample once excited with a sinusoidal dynamic force. These data are used to evaluate the complex elastic modulus of the sample material. The time-temperature superposition principle is applied on the DMA results to built the master curves.

Three-point bending configuration

Tensile configuration

Dual cantilever configuration
EXPERIMENTAL CHARACTERIZATION OF THE VIBRATION-DAMPING PROPERTIES OF SOLID PROPELLANT

Dynamic Mechanical Analyzer (DMA) Procedure

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EXPERIMENTAL CHARACTERIZATION OF THE VIBRATION-DAMPING PROPERTIES OF SOLID PROPELLANT

Comparison of the results

The storage modulus variability as a function of test configuration.

- creep phenomena considered critical for tensile tests
- thermal inertia could affect the capability of the sample to follow the test heating rate on the bending samples
Fully 3D FEM

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SOLID PROPELANT COMPLEX DYNAMIC MODULUS
INTRODUCTION IN VEGA SRMs FEM

MSC NASTRAN solver

- Extremely large size of the FEM
- Huge modal density.

Direct solutions both in time and frequency domain.

\[ f_v = b\ddot{u} = ib\omega u \]

\[ b = Gk/\omega_3 \text{ (or } \omega_4) \]

\[ f_s = iGk\omega \]

\[ \omega_3 \text{ (or } \omega_4) \]
MSC NASTRAN solve

DMAP ALTER to allow the use of modal base solutions for VEGA SRMs operative phases simulation

1. The propellant grain main modes are selected on the base of the modal mass and inertia associated to them

2. The propellant is reduced as a super-element using only the modes with significant effective modal mass and inertia

3. The load acting on the propellant is reduced to the interface between the propellant and the case

4. The modal transient is calculated importing the reduced matrices of the propellant and applying the time variation to the reduced loads and to the physics loads applied to the case
EFFECT OF THE INTRODUCTION OF THE COMPLEX DYNAMIC MODULUS OF ELASTICITY IN THE ZEFIROS FIRING TEST NUMERICAL SIMULATIONS

Check on the Z9 firing test ignition transient simulation.
Four different trends of propellant grain damping with frequency checked:
EFFECT OF THE INTRODUCTION OF THE COMPLEX DYNAMIC MODULUS OF ELASTICITY IN THE ZEFIROS FIRING TEST NUMERICAL SIMULATIONS

The differences are variable with frequency.
They can reach values up to the 70%.
CONCLUSIONS AND FUTURE DEVELOPMENT

• VEGA solid propellant storage modulus increases by increasing the frequency while it is the opposite for the loss factor

• Additional analysis shall be performed to reduce the effect of creep and heating rate on test with DMA

• A specific procedure, based on MSC NASTRAN DMAP ALTERS, has been developed to allow the use of modal base solutions for VEGA SRMs → introduce on VEGA SRMs FEMs a solid propellant damping trend variable with frequency and so coherent with the visco-elastic characterization experimental test data

• The use of structural damping (modal base transient solution) coherent with propellant visco-elastic characterization test data instead of viscous damping (direct transient solution) leads to different of the results in the frequency domain up to the 70%
THANK YOU FOR YOUR ATTENTION

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