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Designing and dynamical simulating of missiles and satellites separation mechanism

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ABSTRACT

The engine and load section separator set is designed cylindrical according to the technical parameters. On the one hand this set connects to the load section and the other hand it connects to the main body or engine section. The thickness of this set in establishment area of explosive ring has decreased locally to be cut by explosive ring. In these conditions the half of separator set remains on the load or moving section and the other parts with engine are separated from moving section.

The speed of separation is created by the springs that have installed inside the separator according to the stored energy inside them and it is necessary that the springs be designed to create the Appropriate relative velocity between the main body and the load section. In every project the mass and inertial specifications of the separation system is specified before and after separation. We can write dynamical equations governing engine and load section before and after separation, with use of the conservation of energy and momentum law. In the analysis, we assume that the engine and load sections only move along the longitudinal axis.

According to the equations and the MATLAB code we obtain the general specification of the system and dynamical attitude of both engine and load section for a real input data, as a result and graph for the linear displacements, velocities and accelerations of both fixed and moving sections. We also designed a Graphical User Interface in MATLAB software to improve the code performance for ease of use as a software system.

KEYWORDS: Dynamical Simulating, Missiles, Satellites, Separation Mechanism

1. INTRODUCTION

The instruments used in separation of engine and cargo are, generally, divided into three categories:

- Fastening and connecting tools;
- Separator tools (spacers); and,
- Auxiliary tools.

Fastening tools and separators are responsible for connecting stages, disconnecting stages after separation order is issued, and providing appropriate distance aimed at prevention of separation stages to conflict. Auxiliary tools are relatively impacting on engine separation process. Types of mechanisms for separation of missiles and spacecrafts are illustrated in the Fig. 1.

Depending on detonation of explosives upon disconnection, fastening and connecting tools are divided into two main classes:

1. Explosive separation system; and,
2. Non-explosive separation system.

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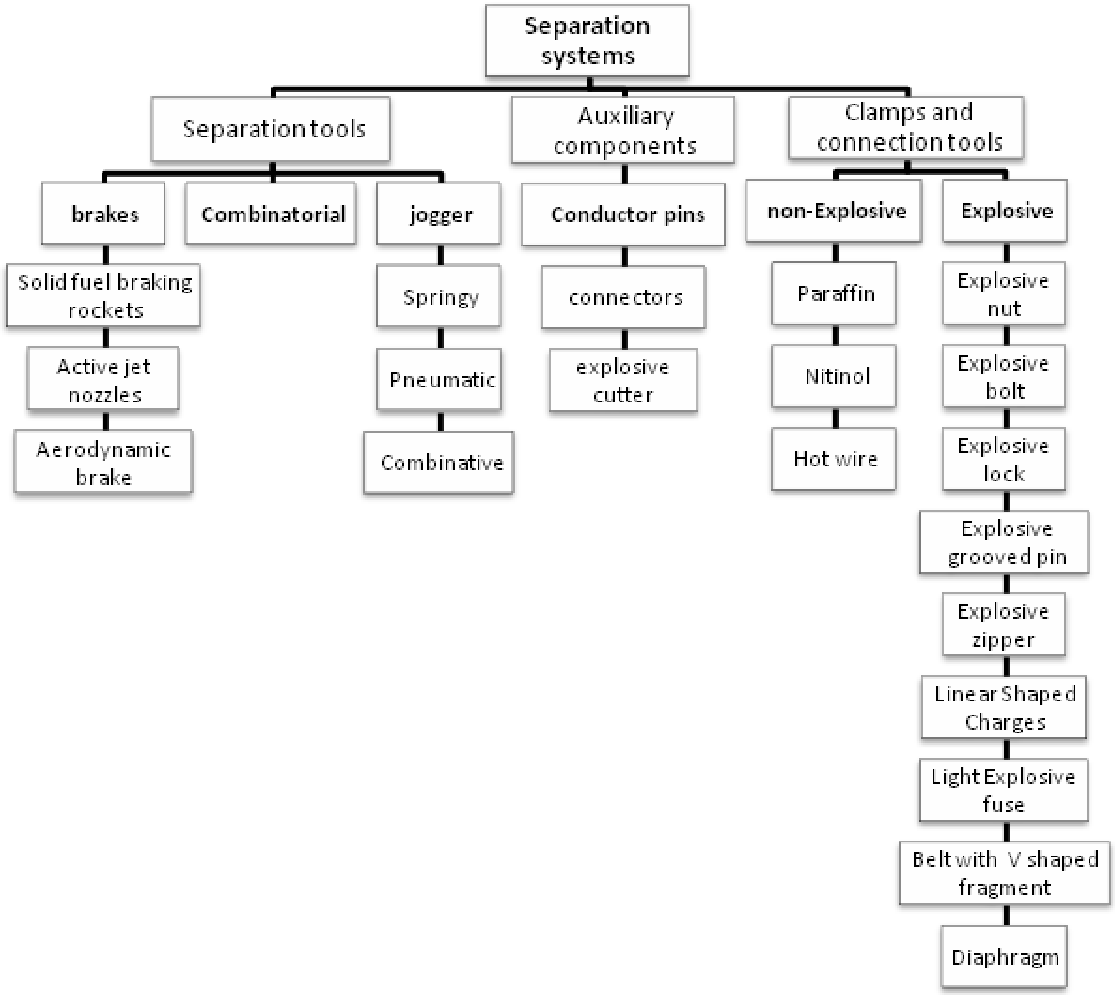

Fig. 1. classification of mechanisms for separation of missiles and spacecrafts

Based on the mechanism applied in driving the two parts off, separator tools can be pigeonholed into three main categories:

1. Pushing;
2. Braking; and,
3. Combination of the two.

2. Essential Considerations in Designation of Separation Mechanisms

Upon designation of separation mechanisms, following factors should be taken into account:

- Permitted clearance between different separation components;
- Shocks transmitted to cargo section;
- Destruction of cargo structure as a result of shrapnel and debris ensuing from performance of separation mechanism;
- Ability of separation to endure natural and environmental conditions upon separation.

Mechanisms for separation of missiles and spaceships should secure continuity of structure upon application of ground and flight loads, separating related components after related commands are issued. They should, furthermore, generate relative velocities required among separated components without application of forces, translocation, tensions, or debris that result in instability. Suitability of structural and operational conditions of separation mechanism is evaluated under real environmental conditions by means of designing, analyzing, and testing, a description and analysis of which will be presented hereunder.

Separation mechanisms should be designed in such a way to endure structural load ranges without plastic transformation or breakage. They should be able to work when commands are issued without re-collision of components or occurrence of breakage/shrapnel. Separation mechanisms should be designed so that their performance assurance meets necessary performance standards. Consequently, following items should be considered upon designation of separation mechanisms.

1. Natural conditions imposed on mechanism;
2. Dynamic properties and stiffness of separation bodies;

3. Operational and physical interference among removable bodies;
4. Mass properties of separation bodies;
5. Practical properties and standards of safety ranges.

Information of similar mechanisms should be applied for fulfilling performance requirements of separation mechanisms mentioned hereunder in order to enable mechanism endure work conditions:

1. Suitable structural continuation before separation;
2. Clearance among removable components;
3. Suitable relative velocity of separation;
4. Maximum permitted deviation ensuing from separation;
5. Operational ability and flexibility at breakage of a part of mechanism.

Mathematical models of separation mechanism and removable bodies should be used for proper simulation of all movements of removable bodies. In analyzing, all occurrences that may probably happen in separation process and leave impact thereon should be taken into consideration, chief among them:

- Inappropriate timing;
- Vibrations;
- Throwing shrapnel;
- Aerodynamic resistance ensuing from different sections;
- Control system response;
- Inappropriate tinder of explosives;
- Moderate translocations;
- Aerodynamic heating;
- Application of pressure onto structure;
- Deviation of rocket's propulsion angle.

3. Proper Selection of Separation Mechanism

In the process for engine-cargo separation, linear shaped charges are used as fastening and connecting tools for separation of engine from cargo. Linear shaped charges are a sort of explosive breakers that make use of Munroe Effect, i.e., focusing of explosion energy by a hollow cut over a surface of explosive. This instrument generates high-speed metal jets that possess high penetrating power, causing very precise cuts at connecting points of structures. It is filled with a hallow channel of powerful explosives and has a tinder and metal veneer with triangular deflection.

Metal veneer is in contact with explosives and causes high pressure at the highest ridge point upon explosions. It, then, moves toward the base. Compressive force causes the metal veneer to melt, generating a high-speed metal jet that is applied perpendicular to the channel. This jet makes a cut along the intended direct, clean line. Amount of shocks and shrapnel is high in this mechanism. Shock load depends on thickness and substance of the body. Determination of the shock load between linear charges and body is very important to enable determination of proper distance by design tests. For further confidence, linear charges are better to be exploded by two-rod tinders. Linear charges should be carried with enough care, since their transformation may cause improper performance. Linear charges are available in different sizes, with some of them being fully flexible. Shrapnel pollutions, in fact, constitute one of the great problems of this type of separation systems.

Spring pushers are among the most common separation tools that generate relative velocity among the two stages used in this collection. In this mechanism, the energy accumulated from spring's compression is utilized as a pushing force. Spring pushers are served to create a safe distance in order to prevent impacts between engine and cargo upon separation. They lack additional components like detonators and electric systems, causing a reduction in reliability. Chief advantage of spring pushers is conduction of primary re-control for determination of their technical specifications. Spring pushers are inexpensive and simple in their production and design, and do not need any special instruction upon their performance. In all engine-cargo separation collections, other additional components are employed together with fastening and connecting tools that vastly influence on the separation process. In cargo, connectors are used as auxiliary tools for connecting cables between separation, cargo, and engine separations.

4. Examination of Engine Separation Theory

Engine-cargo separation collection is designed in cylindrical shape based on technical parameters. This collection is connected to cargo from one side. The collection's thickness is reduced at the area where explosive circle is established in order to allow it to be cut off. Under these circumstances, a half of the engine separation collection remains on cargo or warhead, with other parts being separated together with the motor.

Explosive circle provides the required energy for cutting circle into external diameter and intended thickness. Additionally, engine separation collection is required to be sufficiently strong in order to prevent external loading to cause early separation of the collection from connecting area of explosive circle. Following is a dynamic analysis of the engine-cargo separation.

5. Dynamic Analysis of Engine Separation Collection

Velocity of engine separation is generated with respect to the energy reserved in springs installed therein. Springs should be designed in such a way to generate appropriate relative velocity between engine and cargo. General mass-inertia properties of engine motor separation are specified in each project both before and after the separation. In this section, dynamic calculation of engine separation is expounded in detail. According to the law of conservation of energy and amount of movement before and after separation, dynamic relations dominant on engine and cargo can be formulated. In analysis, this is supposed that engine and cargo move only along the X-axis.

With regard to formulation of the law of conservation of movement before and after separation and as external forces are not applied onto engine and cargo (separation is done in high altitudes and external force is zero), we would have:

$$(m_M + m_p)v = m_M v_M + m_p v_p \quad (1)$$

In this relation, m and V are respectively indicative of mass and velocity, and P and M indices are respectively showing cargo and engine.

Using the law of conservation of energy, we would have:

$$\frac{1}{2}(m_M + m_p)v^2 - \frac{1}{2}m_M {v_M}^2 - \frac{1}{2}m_p {v_p}^2 = \Delta E_s \quad (2)$$

Velocity difference of engine and cargo after separation is specified:

$$v_{rel} = v_p - v_M = 2.5\ m/s \quad (3)$$

Through having equations (1) to (3) and value of cargo mass being known, this is possible to calculate initial speed of cargo and engine, necessary elastic energy, and reserved energy in spring before it is separated. Based on available data, engine and cargo masses upon the separation are regarded as 1,220 and 220 kilograms, respectively. According to energy relation reserved in spring (relation 2) and also geometrical dimensions of separation collection, appropriate spring is selected:

$$K = \frac{2\Delta E_s}{n\Delta x^2} \quad (4)$$

In this relation, *n* is the number of springs, Δx amount of compression, ΔE_s reserved elastic energy, and *K* spring stiffness coefficient.

One of the important parameters in designation of separation mechanism is that system should be designed in such a way that minimum deviation is generated with appropriate initial speed. Therefore, the number of springs used in cargo is supposed to be eight ones, which are installed in engine separation collection in an entirely symmetric manner. However, one individual spring can be placed in the middle of the collection, with its main problem being large size of the spring and necessity of having a spring seat in middle of the collection. This may pose some problems to structure of the spring and necessitate placing a ring for application of force onto the cargo.

According to establishment place of the spring, its diameter and height are usually specified in compressed mode. After some trial and error, suitable spring can be procured. In case cargo velocity at its vicinity to separation is regarded to be zero, spring compression is 50 millimeters, reserved elastic energy is 687.5 Jules, and spring stiffness is 68.9 N/millimeters, this spring collection would be able to apply a relative velocity of 2.5 m/s into the cargo.

For more accurate evaluation of this problem and to assure that the two collections are not collided after separation, a special MATLAB-based code is developed that is able to examine relative velocity, acceleration, and location difference. Following is an elucidation of this code.

As indicated above, velocity of engine separation is generated in accordance with the energy reserved in installed springs therein. Therefore, springs should be designed so that an appropriate relative velocity is generated between cargo and engine. If x_f and x_m are locations of points of the engine separation collection attached to engine and cargo before separation, whose values are identical before separation, value of x_m would grow higher than x_f after separation. Their difference would be equal to the distance between movable and fixed parts that is marked with x and is equal to:

$$x = x_f - x_m \quad (5)$$

Spring force, which is applied onto movable and fixed parts with equal values and in opposite direction, is equal to:

$$F_k = k(\delta_0 - x) \qquad (x \le \delta_0) \quad (6)$$

Where, F_k is spring force, *k* stiffness of all springs, *x* the distance between cargo and engine levels, and δ_0 value of spring's primary compression. Disregarding aerodynamic forces at the altitude of 90 kilometers above the ground, acceleration of fixed and movable parts is:

$$\ddot{x}_f = \frac{k}{m_f}(\delta_0 - x) \quad (7)$$

$$\ddot{x}_m = -\frac{k}{m_m}(\delta_0 - x) \quad (8)$$

Replacing relations (7) and (8) in second-order derivative of relation (5) in time terms, we have:

$$\ddot{x} = \ddot{x}_f - \ddot{x}_m = \left(\frac{1}{m_m} + \frac{1}{m_f}\right) k\left(\delta_0 - x\right) = \frac{k}{m_{eq}}\left(\delta_0 - x\right) \tag{9}$$

Where, m_{eq} is defined as:

$$\frac{1}{m_{eq}} = \frac{1}{m_m} + \frac{1}{m_f} \tag{10}$$

Thus, relative velocity between movable and fixed sections is obtained from the integral equation of the relation (9), that is:

$$\dot{x} = \sqrt{\frac{2k}{m_{eq}}\left(\delta_0 x - x^2/2\right)} \tag{11}$$

The distance between two movable and fixed sections is obtained from the integral equation of the relation (11), and application of primary conditions is determined as follows:

$$x = 2\delta_0 \sin^2\left(\frac{t}{2}\sqrt{\frac{k}{m_{eq}}}\right) \tag{12}$$

The acceleration generated in movable and fixed sections in terms of time is determined by replacement of the relation (12) in relations (7) and (8), that is:

$$\ddot{x}_f = \frac{k}{m_f}\delta_0\left[1 - 2\sin^2\left(\frac{t}{2}\sqrt{\frac{k}{m_{eq}}}\right)\right] = \frac{k}{m_f}\delta_0 \cos\left(t\sqrt{\frac{k}{m_{eq}}}\right) \tag{13}$$

$$\ddot{x}_m = \frac{-k}{m_m}\delta_0\left[1 - 2\sin^2\left(\frac{t}{2}\sqrt{\frac{k}{m_{eq}}}\right)\right] = \frac{-k}{m_m}\delta_0 \cos\left(t\sqrt{\frac{k}{m_{eq}}}\right) \tag{14}$$

Velocity of fixed and movable sections is determined by making integral equation of relations (13) and (14) and application of primary conditions, as follows:

$$\dot{x}_f = V_0 + \frac{\sqrt{km_{eq}}}{m_f}\delta_0 \sin\left(t\sqrt{\frac{k}{m_{eq}}}\right) \tag{15}$$

$$\dot{x}_m = V_0 - \frac{\sqrt{km_{eq}}}{m_m}\delta_0 \sin\left(t\sqrt{\frac{k}{m_{eq}}}\right) \tag{16}$$

Where, V_0 is the primary velocity of collection in pre-separation phase. As a result of opening of springs, velocity of movable section is increased and that of its fixed one decreased. When primary compression of springs is totally moved out and springs reached their basic conditions, both collections start to move at this moment with a fixed velocity. The time required for complete opening of springs is calculated as the relation (12):

$$\sin^2\left(\frac{t}{2}\sqrt{\frac{k}{m_{eq}}}\right) = \frac{1}{2} \tag{17}$$

Therefore, velocity of fixed and movable sections is determined after springs reach their primary length through replacement of the relation (17) in relations (15) and (16), that is:

$$V_f = V_0 + \frac{\delta_0\sqrt{km_{eq}}}{m_f} \tag{18}$$

$$V_m = V_0 - \frac{\delta_0\sqrt{km_{eq}}}{m_m} \tag{19}$$

Numerical value of cargo mass, stiffness of each spring, and primary compression of springs in engine separation plan are taken into account as shown below:

$$k = 8\times55730\,N/m,\quad \delta_0 = 0.05m,\quad m_f = 1220kg,\quad m_m = 220kg \tag{20}$$

Cargo's velocity-acceleration diagram upon engine separation at different times is exhibited in the Fig. 2.

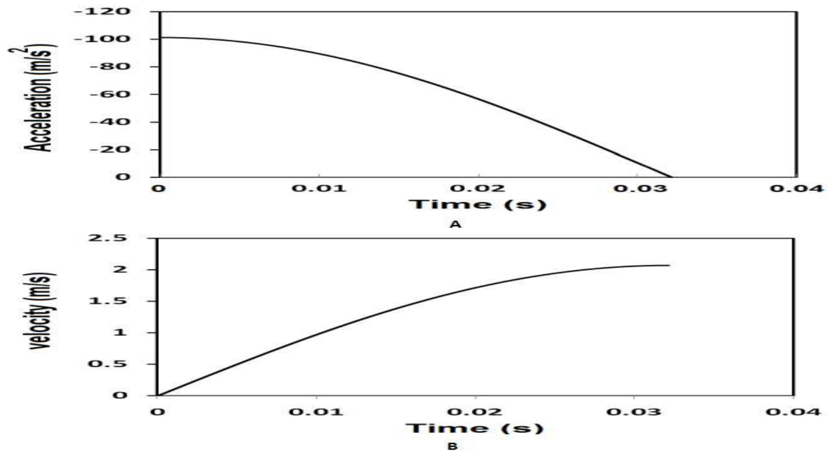

Fig. 2. Cargo's velocity-acceleration diagram upon engine separation at different times

6. Stages for Separation System Dynamic Simulation Software Development

In this section, stages for development of the Separation System Dynamic Simulation Software are explained. Through designation of user graphic interface for codes written in MATLAB, efficiency of this software was improved for convenience of its users. As shown in the Fig. 3, this software includes a section for entering primary data, which is transferred into computation section by designed textboxes. Afterwards, required calculations are performed and outputs are displayed as diagrams in six different sections. Their numerical values can, also, be observed in textboxes placed under the diagrams.

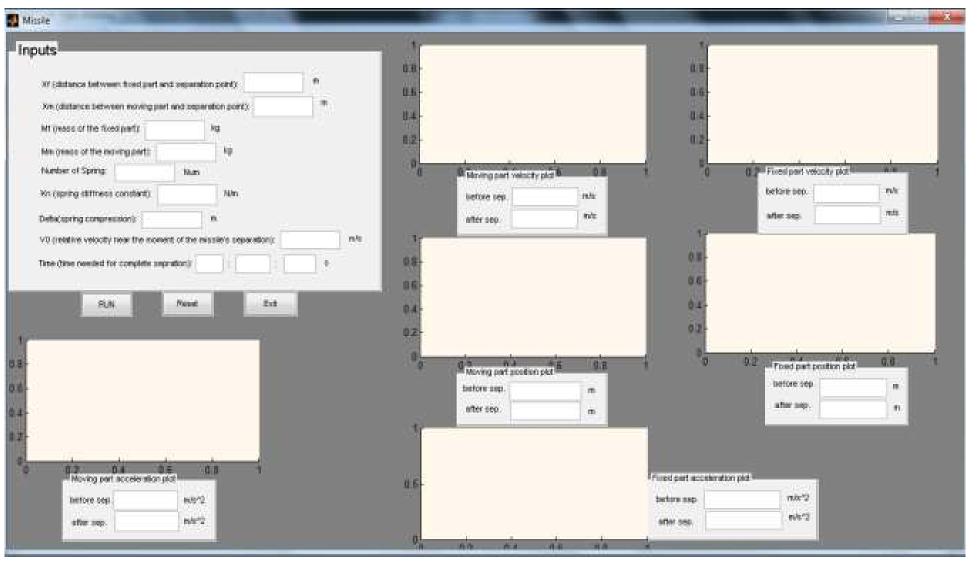

Fig. 3. separation dynamic simulation software user interface

In data entry section, three buttons *Run*, *Reset*, and *Exit* are placed. *Run* button is responsible for initiating calculations after required data is entered by user, to whom outputs are, finally, presented (Fig. 4).

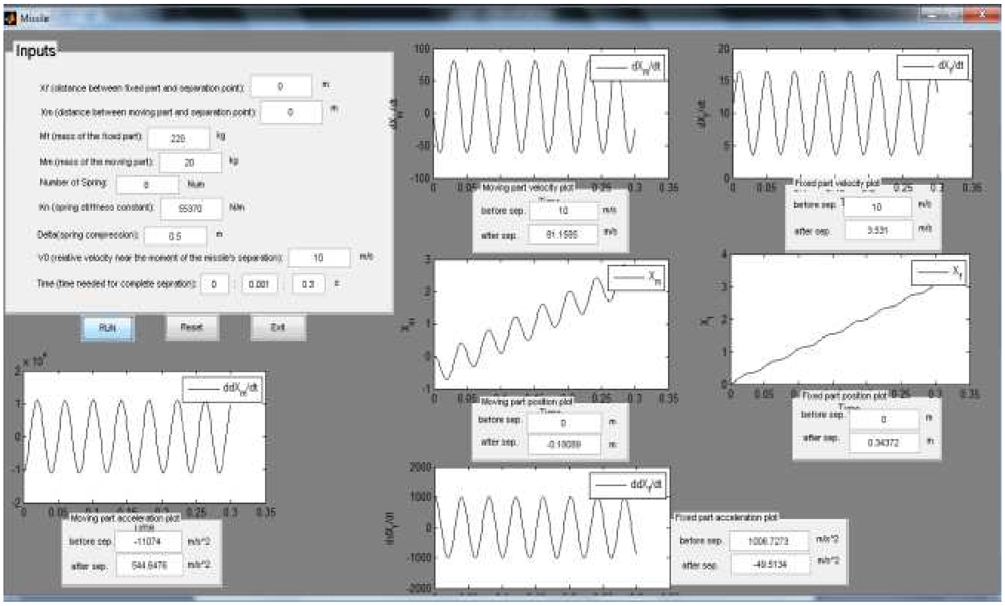

Fig. 4. performance of graphic interface of separation dynamic simulation software after RUN is pressed

Reset button enables user to readdress environment for making reuse of software, entering new information for re-calculations. *Exit* button, finally, closes the software and redirects to the OS.

9. Conclusions

According to above-mentioned relations, general specifications of engine separation collection are as follows:

- Displacement of upper half of engine separation collection until complete separation is 38 millimeters;
- The time required for complete engine separation after sending electric command to detonators is 32 milliseconds;
- Relative velocity between upper half of engine separation and cargo after complete separation is 2.5 m/s;
- Cargo's acceleration at separation moment is 101.25 m/s^2.

Additionally, figures 5 to 10 demonstrate diagrams of displacements, velocities, and linear acceleration for both cargo and engine, or the same movable and fixed sections.

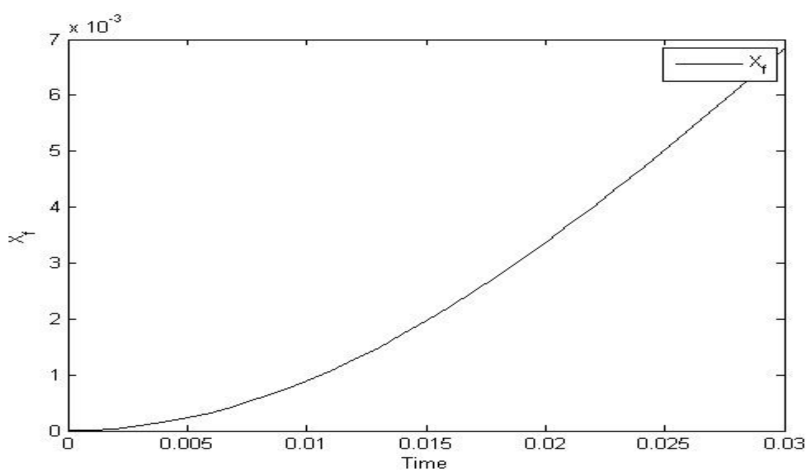

Fig. 5. location change diagram of fixed section (engine) at different times

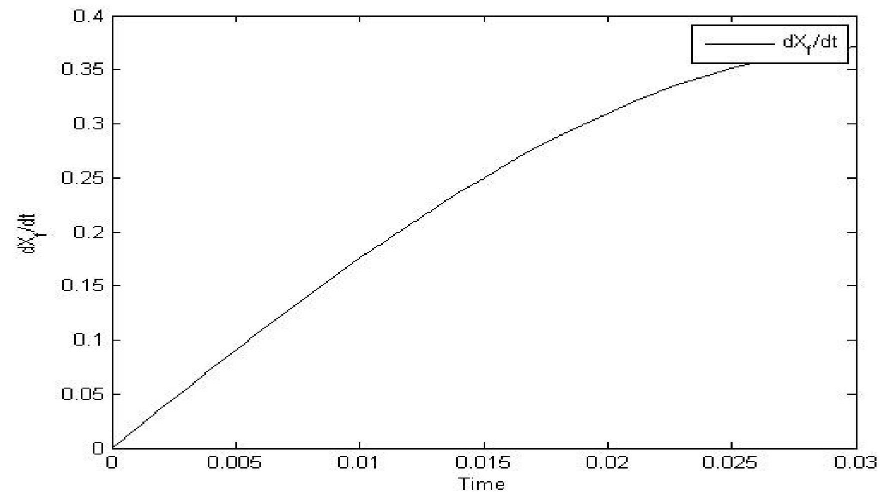

Fig. 6. velocity diagram of fixed section (engine) at different times

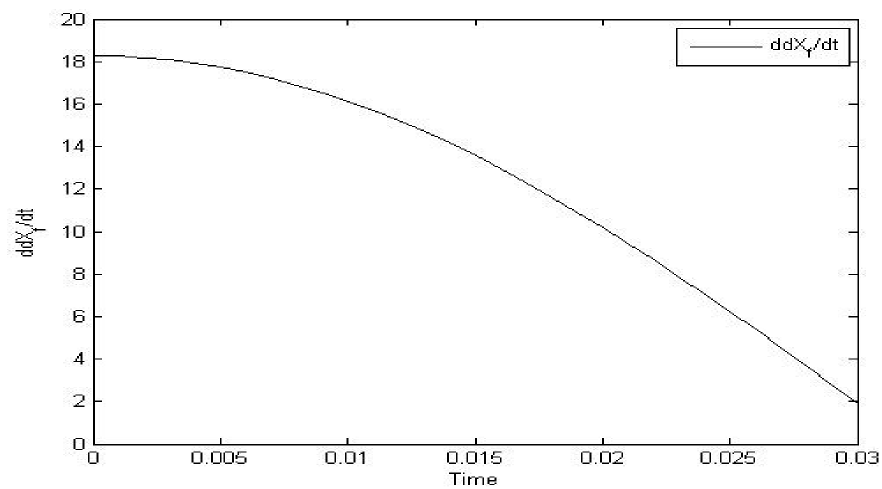

Fig. 7. acceleration diagram of fixed section (engine) at different times

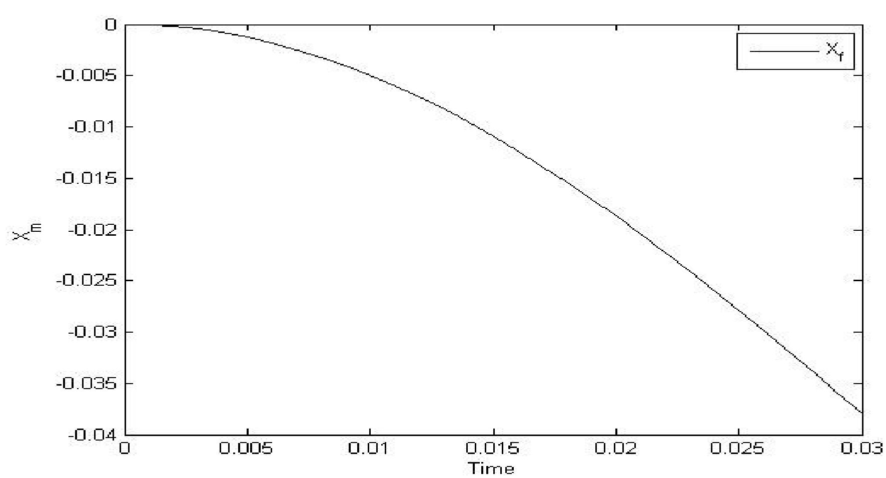

Fig. 8. location change diagram of movable section (cargo) at different times

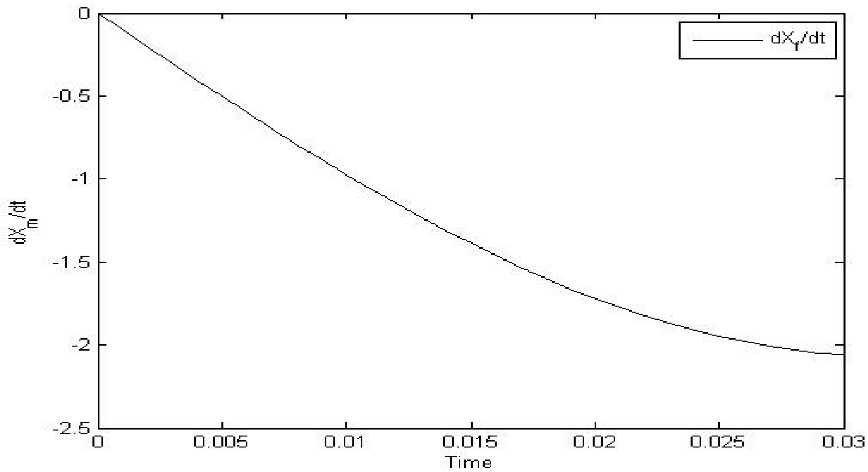

Fig. 9. velocity diagram of movable section (cargo) at different times

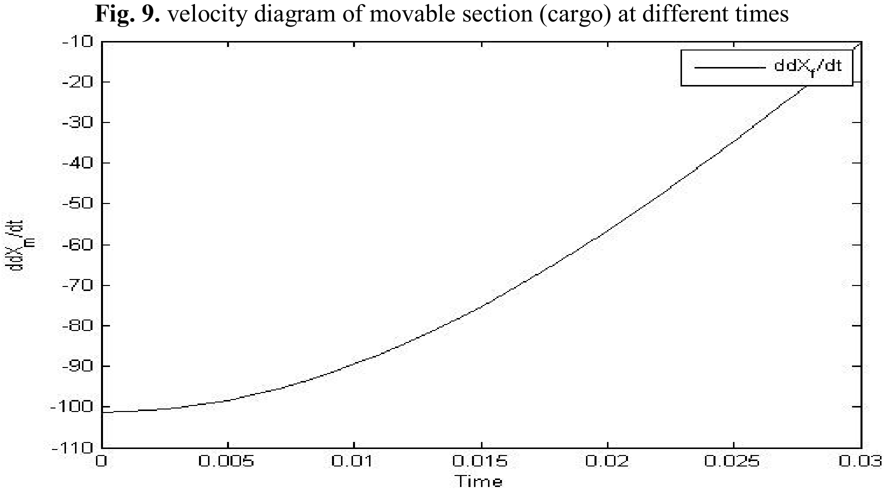

Fig. 10. acceleration diagram of movable section (cargo) at different times

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