Defence Science Journal, Vol 42, No 1, January 1992, pp. 23-28

Design Optimisation of Parachute Sequencer Mechanism

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ABSTRACT

Attempt has been made to ascertain the behaviour of complex continuous system of parachute sequencer mechanism by discretisation. Parachute sequencer mechanism consists of different kinematic linkages which are subjected to shock loads, imposed by parachute deploying at very high velocities. Dynamic properties of various linkages have been studied by establishing equations. The effects of modifying various parameters have been discussed. A computer programme has also been written to study the effects of the changes in variables to arrive at optimum solution. The method followed and the findings are enumerated.

NOMENCLATURE

A	area of parachute
C_D	coefficient of drag for parachute
F	force in newton
F_k	force required to sustain the motion
F_s	force required to initiate the motion
f	frictional force = μN
N	normal reaction
S	spring force
V	instantaneous velocity
θ	semi angle of plunger
μ	coefficient of friction
μ_k	kinetic coefficient of friction
μ_s	static coefficient of friction
ρ	density of air

Received 19 February 1990, revised 25 May 1991

1. INTRODUCTION

Retardation is essential to obtain the desired trajectory, attitude of weapon and required safety distance between parent aircraft and the point of explosion of weapons which are released in low level, high speed attack mode, from the aircraft. Retardation is usually achieved by a parachute system. Parachute squencer mechanism (PSM) is required to separate smaller (drogue) parachute from the weapon and to deploy the main parachute. It is assembled with weapon, by extension of spring loaded plungers and provides anchor to drogue parachute (Fig. 1). The deployment and operation of drogue parachute exerts the load of 8-10 tons on PSM. It deploys the main parachute after predetermined delay. This is done by withdrawing the plungers, at fixed time using the stored energy in springs against the force of drogue parachute. The PSM designed earlier was unable to deploy the main parachute. The design was subjected to macro analysis[1] by discretisation method. Based on the report of analysis, optimisation of the design was carried out successfully. The method followed and the findings

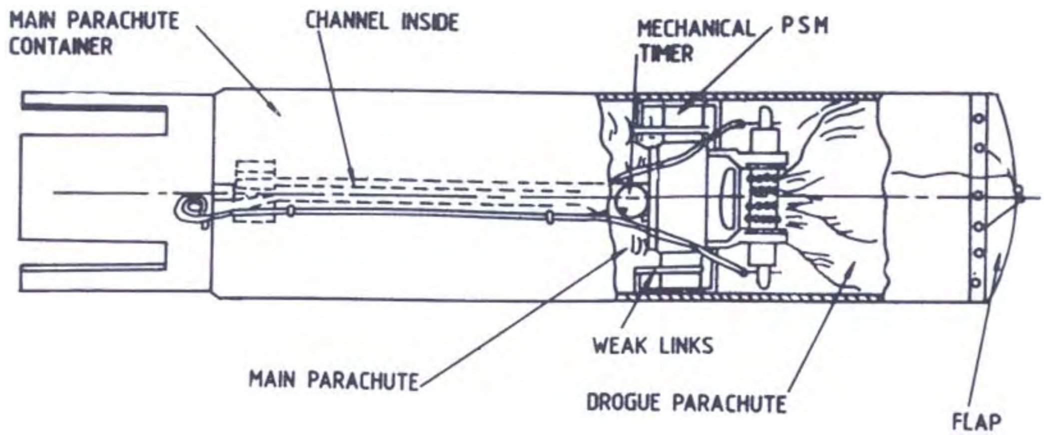

Figure 1. Parachute sequencer

during evolution of optimisation are enumerated in this paper.

1.1 Assumptions

The following assumptions were made for this study.

(a) The weapon is being released in lay down, high speed, and low level attack mode;

(b) The release velocity is 1000 kmph (277.77 m/s);

(c) The release height is 50 m ATL;

(d) The density of air (ρ) is 1.25 kg/m^3;

(e) The coefficient of drag of the parachute (C_D) is 0.6;

(f) The instantaneous velocity at the time of deployment of main parachute (V) is 100 m/s (approx);

(g) The force on plungers (F) during withdrawal is considered as constant;

(h) The semi angle of plunger (θ) is 10°; and

(i) The deployment of parachute is instantaneous so that the severity of load is maximum.

2. DISCRETISATION

To ascertain the behaviour of complex continuous system with some sort of approximation has fascinated scientists and engineers. For simple elements like uniform beams, plates etc classical solution can be sought by forming differential and/or integral equations through the concept of infinitesimal element. Real structures like machine tool frames, aircraft structures, pressure vessels, automobile bodies, domes etc need some approximate treatment to arrive at their behaviour, be it static deformations, dynamic properties, or heat conducting properties. The classical differential equation solution approach leads to complex mathematical relations and intractability. The behaviour of such systems can be studied by discretisation method. The actual complex structure is defined using a finite number of well defined components. Such systems are then regarded as discrete systems. The method was applied to study the dynamic behaviour of PSM.

3. ASSEMBLY AND OPERATION OF PSM

Figure 2 shows the details of the assembly and operation of PSM. The attachment block with drogue parachute is removed for assembly of PSM to the weapon. The mechanical timer is fully wound. The withdrawal pin is locked to the timer with a locking wire of 60–80 N breaking load. The cocking tool is assembled to PSM. The tool engages the central spider with 2 bolts. The linkages of main parachute are engaged to PSM. The PSM is placed in position inside the retarder unit container. The spider is pulled down till it rests on the rear cover during cocking. The movement of spider extends the plungers to assemble with weapon by compressing the plunger springs. The groove in spider aligns with the steel balls. The timer sleeve is pulled down with a special tool, compressing the timer sleeve spring and is locked in position by the locking pin. Timer is unwound slightly and sector moves and rests against the withdrawal pin during the process, thus avoiding over-winding of timer. The timer sleeve presses out the steel balls housed in the rear cover. The protruding balls lock the spider and thereby keep the plungers in place. The sector of timer is held in place by withdrawal pin. The release wire engages the withdrawal pin at one end and aircraft pylon at the other end.

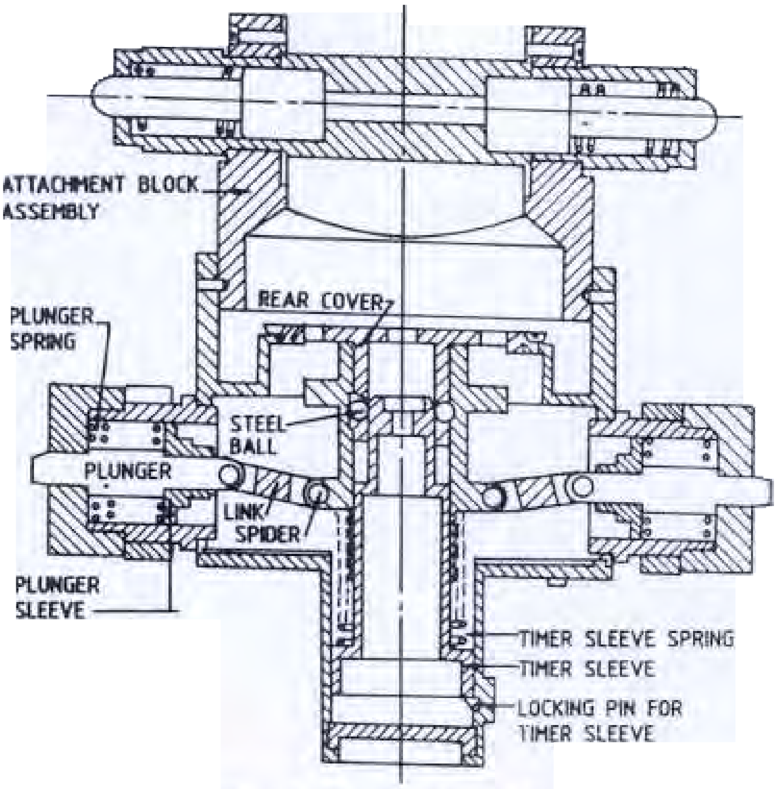

Figure 2. Retarder unit assembly

On release of the weapon from aircraft the withdrawal pin of PSM is pulled out of timer and simultaneously the drogue parachute is also deployed. The sector starts rotating and provides the required delay. On rotation of sector, the timer sleeve is freed. The compressed timer sleeve spring exerts and pushes the timer sleeve out of the rear cover. The steel balls are free to move inside. The energy stored in plunger springs moves out the spider and plungers are withdrawn against the drogue parachute load. The free PSM is pulled out of weapon by the drogue parachute and in turn the main parachute is deployed.

The PSM at this stage used to fail in deploying the main parachute. The kinematic link assembly of PSM was subjected to macro analysis[1] as discussed further. The guidelines given in the rational procedure for design[1] were also used.

4. DYNAMIC CONSIDERATIONS

The behaviour of various linkages of PSM when considered simultaneously is complex. Therefore, to determine dynamic properties of various linkages of PSM, their continuous system was broken down into components and the force structure was studied (Fig.3).

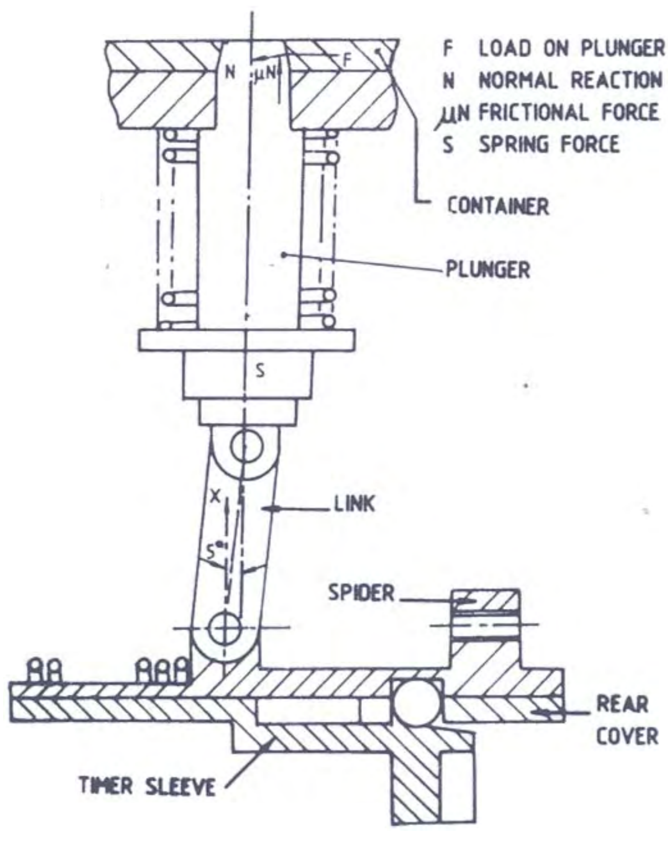

Figure 3. Force structure.

5. SHOCK LOAD OF PARACHUTE

The shock load of parachute is calculated by the formula

$$F = 1/2\,\rho\, C_D A V^2 \qquad (1)$$

Substituting the values A = 3.28 m^2 and V = 277.77 m/s (1000 kmph) in Eqn (1) we get F = 90869.64 N.

The PSM has to withstand this load without suffering any kind of permanent structural damage. By substituting V = 100 m/s in Eqn (1), the load on plungers when they are withdrawing to deploy main parachute is obtained as F = 11776.70 N. Taking safety factor into consideration it is intended that the plungers should withdraw at a load of 19620 N.

6. STUDY OF FORCE STRUCTURE OF PLUNGER

The load of 19620 N is shared by four plungers. The load on each plunger is 4905 N. Fig.4 indicates the assembly of a PSM plunger and weapon. Resolving the forces along N and f, we get

$$N = F\cos\theta - S\sin\theta \qquad (2)$$

$$f = \mu N = F\sin\theta + S\cos\theta \qquad (3)$$

Dividing Eqn (3) by Eqn (2) and simplifying, we get

$$S = F(\mu\cos\theta - \sin\theta)/(\cos\theta + \mu\sin\theta) \qquad (4)$$

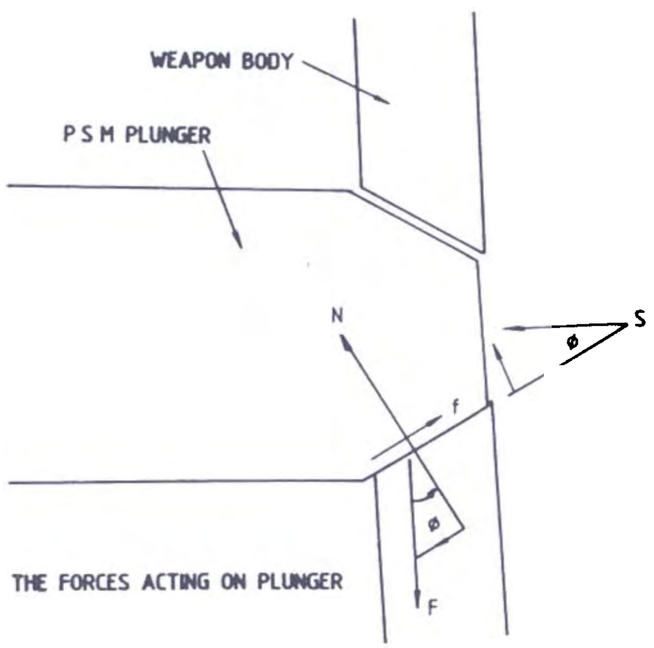

Figure 4. The study of force structure of plunger.

7. CONSIDERATION OF VARIABLES

Examination of Eqn (4) reveals that withdraw plungers depends on spring force (S), coefficien friction (μ), and semi-angle of plungers (θ).

7.1 Spring Force (S)

Substituting the values μ = 0.8 (coefficient of fri of steel on steel), F = 4905 N, and θ = 10°, we obta S = 2680.93 N.

Considering constraints like space, asse problems and load coming on other parts in the sys the above value of spring strength is consid impractical.

7.2 Coefficient of Friction (μ)

In the Eqn (4) it is apparent that the value of sp strength depends considerably on coefficient of fric (μ).

7.3 Sliding Friction

Withdrawal of plungers is caused by sliding mo under load. In this movement, sliding friction pla major role which is primarily a surface phenomen It depends on surface conditions like roughness, de of work hardening, type of oxide film and sur cleanliness. In sliding friction surface, contamina has a profound effect which is true particularly surfaces that are nominally clean. Very wide differe in friction may be obtained under apparently sin conditions, especially with unlubricated surfaces.

The tangential force required for motion of one b over other has a critical value (F_s). This represents condition of micro displacement before gross sli occurs.

If F_s is the force required to initiate the motion F_k is the force required to sustain the motion, the

$$\mu_s \quad F_s / N$$

and $\quad \mu_k = F_k / N$

$$\mu_s \geqslant \mu_k$$

The study for a suitable coefficient of friction was undertaken which resulted in the following:

Tables 1 and 2 reveal that teflon has lowest coefficient of friction ($\mu_s = 0.05$) therefore teflon coating was applied on all load bearing parts. In functional tests PSM has functioned at loads of 19620 N and above. However, teflon has a tendency to flow under initial application of load[3]. It is not mechanically strong and has a high coefficient of expansion. During repeated tests, the coating used to peel off and form clots, hindering operation of PSM. Therefore, the use of teflon coating was discontinued.

Table 1. Unlubricated metals prepared grease free[2]

Metal	Static coefficient of friction (μ_s) Pure metal on steel*	
Ag	0.5	
Al	0.5	
Cd		
Cu	0.8	
Cr	0.5	
Fe		
In	2.0	
Mg		
Mo	0.5	
Ni	0.5	
Pb	1.2	
Sn	0.9	
Pt		:3

*0.13 *C'* and 3.42 *Ni* normalised.

Table 2. Mild steel lubricated with protective film[2]

Protective film	μ_s	Temperature upto which lubrication is effective 0°C
Teflon, fluon (PTFE)	0.05	320
Graphite	0.07–0.13	600
Molebdenumdisulphate	0.07–0.1	800

7.4 Semi-Angle of Plungers (θ)

The engagement to weapon is of the form similar to cone clutch. If the angle of surface is too small it may be difficult to disengage on account of wedging effect whereas, if the angle is too large excessive spring pressure will be required to prevent slipping[4]. The minimum angle required is about 8–9° and maximum about 13°. The angles are with reference to axis and are half the included angles. Therefore, the angle of 10° was considered to be of good practice and retained.

8. FINDINGS AND SOLUTION

It was evident from the work done that effecting a change in only one variable has not led to solution. Optimum combination of these variables was required to be arrived at. So, a computer programme was developed to study the effect of variation of these factors and to find the best combination. The flow chart of the computer programme is shown in Fig. 5. The results were studied and the values were compared with those values which can be practically achieved.

The values selected were, (i) spring force (1177.2 N): a combination of two springs 981 N and 196.2 N, one

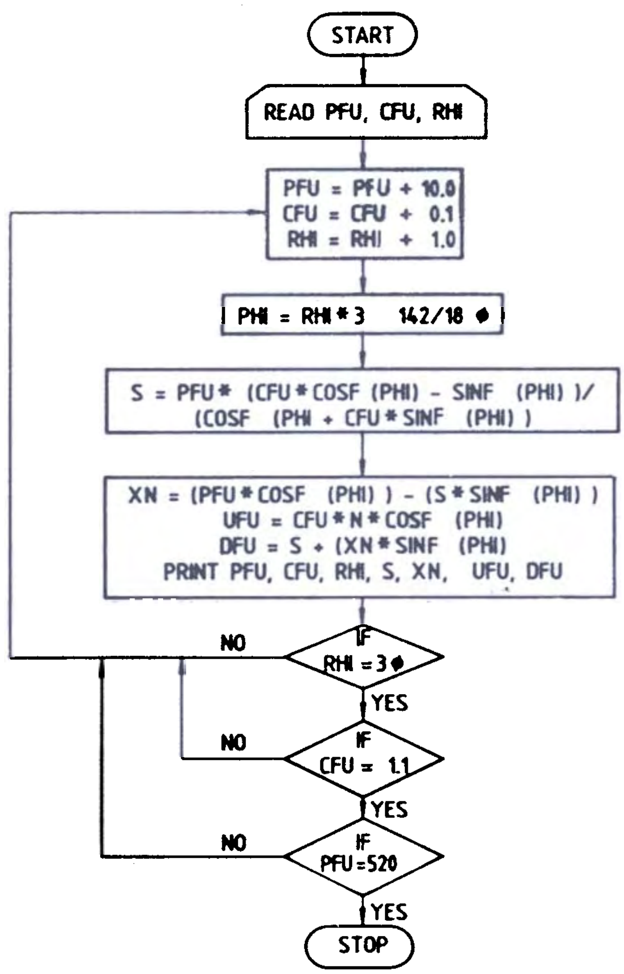

Figure 5. **Flow chart of the computer programme PFU: force exerted by parachute, CFU: coeffcient of friction, RHI: semi-angle of plunger, XN: normal reaction, UFU: upward force, DFU: downward force**

left hand wound and other right hand wound assembled inside each other; (ii) semi-angle of plunger (10°) and (iii) ground finish and bright chrome plating to bring down the coefficient of friction (0.4).

The additional advantage of bright chrome plating is that the surface remains rust-free and clean, avoiding very wide differences in friction. Thus the consistency of operation improves tremendously along with asthetic look.

Substituting the above values in Eqn (4) we get $F = 5634.18$ N, which is more than the required 4905 N.

Table 3. Test results

Assembly No.	Max. load (ton)(176.58 kN)	Load at which locking pin removed (ton) (39.24 kN)	Load at which plungers withdrawn (ton)
85	18.0	4.0	3.0 (29.43 kN)
89	18.0	4.0	4·0 (39.24 kN)
90	18.0	4.0	2.6 (25.50 kN)
91	18.0	4.0	4.0 (39.24 kN)
93	18.0	4.0	4.0 (39.24 kN)

9. CONCLUSION

The PSM manufactured with above modifications were subjected to functional tests on UTM. All PSM plungers have withdrawn at loads of 19620 N and above, and the results have been given in Table 3.

A large number of weapons were released in flight trials with these PSM at various release speeds. A total of 75 per cent of these PSM have functioned successfully proving the efficacy of equation and modification.

ACKNOWLEDGEMENTS

The author is grateful to Air Cmde NN Shah, Head, Air & Navy Division for his encouragement and guidance in the preparation of this paper.

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