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RESEARCH ON OPTIMIZATION TECHNOLOGY FOR CONTROL PARAMETERS OF EJECTION SEAT BASED ON PSO ALGORITHM

Lou Jin[1,2], Ming Wu[1,2], Hui Yang[1,2], Liang Wu[1,2], Dongyue Cui[3]

[1]Overall Technology R&D Department, AVIC Aerospace Life-support Industries, Ltd., Xianyang 441000, China
[2]Aviation Key Laboratory of Science and Technology on Life-support Technology, Xianyang 441000, China
[3] Institute of mechanical and electrical system, AVIC The First Aircraft Institute, Xi'an 710000, China

Abstract

This article studies the optimization simulation method of the multi-modal control parameters of a certain type of ejection seat. According to the working mechanism and optimization goals of the seat, based on the particle swarm optimization algorithm, an optimized simulation program is designed. Using an optimization simulation program written by the Matlab/Simulink platform, the preliminary determination, screening and iterative optimization of control parameters were completed. The optimization results show that by optimizing the multi-modal control parameters, the life-saving performance of the seat is increased by 12.5%, which verifies the effectiveness and feasibility of the optimization algorithm, and provides a theoretical basis for future seat development and modification. .

Keywords: ejection seat, multi-modal control, optimization simulation, optimization method, PSO algorithm.

1. Preface

With the development of ejection life-saving technology, improving the life-saving capabilities of ejection seats under low-altitude and unfavorable posture conditions has become an important task in the development of ejection seats. The key to solving this problem lies in real-time control of the movement posture of the ejection seat. A certain type of ejection seat adopts a multi-parameter and multi-modal control program, which is based on simulation calculations of a large number of working conditions and manual analysis by technical engineers. There are many state parameters for multi-modal control, and the division of each control mode is also very complicated, and there is no sufficient theoretical basis for determining the critical value of each control parameter.

At present, the research on seat control parameters and control mode design has a certain foundation. Mao Xiaodong[1] proposed a design method of ejection seat control law. According to the trajectory and posture simulation model of the entire seat ejection process and the design control parameter optimization calculation model, the discretized optimal control parameter set was obtained. Then, using the neural network model based on the error back propagation algorithm, the continuity control law algorithm for the entire range of the ejection state was obtained, and the control law algorithm was simulated and verified; Zhang Minghuan[2] studied an attitude control algorithm of the "H" rocket pack ejection seat, simulated the different ejection states of the seat, and analyzed the influence of the control algorithm on the lifesaving performance of the seat ejection , and evaluated it in accordance with the relevant regulations of the NMS, which proved the feasibility and practicability of the control algorithm. However, these studies are often based on third-generation seats or concept seats, and fewer control parameters are considered. Research based on new-type seats is still insufficient. In this paper, the optimization of seat multi-modal control parameters is to improve the lifesaving performance of the ejection seat at the minimum safety height, in order to find the optimal combination of control parameters. The particle swarm optimization algorithm is adopted, a group of control parameters to be optimized is regarded as a particle, and the minimum safety height compliance degree is regarded as the fitness value of the particle, so as to meet the input and output conditions of the particle swarm optimization algorithm, and the global optimal value of the control parameter can be obtained after the simulation calculation.

2. Dynamic model of ejection seat

The main difference between a certain type of ejection seat and the traditional ejection seat is that there is a pair of symmetrically installed attitude rockets, which can control the work of the attitude rockets according to the preset working mode, so as to adjust the seat movement attitude and improve the life-saving performance. When the attitude rocket is working, the seat is in the free flight stage. At this stage, the six-degree-of-freedom dynamic equation of the human-seat system in the body axis coordinate system is

$$\begin{bmatrix} \frac{dv_{xt}}{dt} \\ \frac{dv_{yt}}{dt} \\ \frac{dv_{zt}}{dt} \end{bmatrix} = \begin{bmatrix} \frac{F_{xt}}{m} + \omega_{zt} v_{yt} - \omega_{yt} v_{zt} \\ \frac{F_{yt}}{m} + \omega_{xt} v_{zt} - \omega_{zt} v_{xt} \\ \frac{F_{zt}}{m} + \omega_{yt} v_{xt} - \omega_{xt} v_{yt} \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} \frac{d\omega_{xt}}{dt} \\ \frac{d\omega_{yt}}{dt} \\ \frac{d\omega_{zt}}{dt} \end{bmatrix} = \begin{bmatrix} \frac{\sum M_{xt} + (I_y - I_z)\omega_{yt}\omega_{zt}}{I_x} \\ \frac{\sum M_{yt} + (I_z - I_x)\omega_{zt}\omega_{xt}}{I_y} \\ \frac{\sum M_{zt} + (I_x - I_y)\omega_{xt}\omega_{yt}}{I_z} \end{bmatrix} \tag{2}$$

In the formula, ω is the angular velocity of the human-chair system; m is the mass of the human-chair system; F is the force of the human-chair system; M is the moment of the human-chair system; I is the moment of inertia of the human-chair system. Since the attitude rockets are configured in pairs, the direction of the torque generated by them is set according to the actual situation during the calculation.

3. Particle swarm algorithm and its application

3.1 Principle of particle swarm algorithm

The concept of particle swarm optimization is relatively simple, and it can perform optimization calculations for multi-objective optimization problems. The particle swarm algorithm is easy to program and calculate on the computer, and it has few restrictions on the optimization problem. It can be optimized and solved without knowing the specific expression of the optimization problem. The particle swarm algorithm has fast calculation speed and strong search ability, and it can often overcome the local optimal and obtain the global optimal solution. Using particle swarm algorithm for optimization simulation calculation can quickly obtain the optimal combination of seat control parameters.

The particle swarm algorithm originally originated from the exploration of the foraging phenomenon of birds. The process of particle swarm algorithm searching for the optimal solution in the solution space is the process of birds searching for food. Each particle can be regarded as a bird, and the optimal solution to the optimization problem is the food the birds are looking for[3]. The particle swarm optimization algorithm relies on a group of special particles to perform evolutionary solutions. The particles have speed, position and their own fitness value. The velocity and position of the particle in the search space are determined according to the following formula [4]:

$$\begin{aligned} v_{t+1} &= \omega v_t + c_1 r_1 (P_t - x_t) + c_2 r_2 (G_t - x_t) \\ x_{t+1} &= x_t + v_{t+1} \end{aligned} \tag{3}$$

Where x is the position of the particle; v is the velocity of the particle; ω is the inertia weight factor; c_1, c_2 are the learning factor; r_1, r_2 are the random value in the interval $[0,1]$; P_t is the optimal parameter searched so far by the particle; G_t is the search so far for the entire particle swarm to the optimal parameters.

3.2 Fitness function and constraint setting

The minimum safety height refers to the lowest ejection height that can guarantee the pilot to get a safe life-saving when the seat is ejected, and it is an important index to measure the life-saving performance of the seat ejection. There are 120 initial states listed in the NMS(national military standard). The more states that the seat performance meets the NMS, the better the ejection life-saving performance of the seat.

There are 32 high-speed states in the NMS, where the aircraft's gauge speed is not less than 850km/h. When ejecting at high speeds, the human-chair system is subject to a large aerodynamic force. Adjusting the multi-modal control parameters has a very limited impact on the minimum safety height. Therefore, this article selects only 88 low-speed states in the NMS to measure the effect of improving seat performance after optimization.

The fitness function is the objective function to be optimized, which is determined by the specific optimization problem. The fitness function in this paper is defined as: when the control parameter of the seat is the value corresponding to a certain particle, the number of states that the minimum safety height of the seat meets the 88 low-speed states of the NMS. This function is denoted as N. During the optimization simulation process, the fitness function can be adjusted according to the optimization calculation requirements. After each iteration of the particle swarm algorithm, the optimization result needs to be judged once. If the preset fitness function value (fitness value) and the maximum number of iterations are reached, the iteration is stopped and the result is output. In this paper, the fitness value is set to N=88, that is, to find the control parameter combination with the most number of optimization results that meet the NMS state, until the calculation reaches the maximum number of iterations.

The optimization of seat control parameters must have a basic premise, that is, to ensure that under the new control parameters, the pilot's overload during the entire ejection process is within a certain range, and the multi-axis dynamic response index $\mathrm{MDRC} \leq 1$ [5][6]7]. This is also the constraint condition of the control parameter optimization problem.

3.3 Optimization scheme

According to the characteristics of the particle swarm optimization algorithm, the optimization calculation of the control parameters is carried out according to the following scheme(Figure 1):

- Step1, according to the importance of the control parameters to the seat, screen out the control parameters to be optimized;

  Step2, according to the filtered control parameters, initialize the values of all control parameters in the particle swarm and the change step vector (generated randomly around the original control parameter values of the seat to improve the optimization efficiency), and determine the initial optimal control parameters P_t and G_t;

- Step3, compare the minimum safety height compliance degree under each group of control parameters with the minimum safety height compliance degree under the optimal parameters P_t. If the degree of satisfaction is higher, it will be updated to the current optimal parameter value;
- Step4, compare the minimum safety height compliance degree under each group of control parameters with the minimum safety height compliance degree under the optimal parameters G_t. If the degree of satisfaction is higher, it will be updated to the current optimal parameter value;
- Step5, update the velocity and position of the particles according to formula (3);
- Step6, when the number of iterations reaches the maximum number of iterations or the minimum safety height compliance degree is greater than the set threshold, exit the algorithm

and get the optimal solution; otherwise, return to step 2.

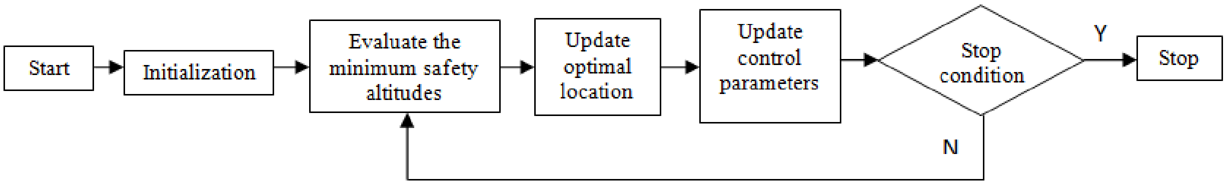

Figure 1 Flow chart of particle swarm optimization algorithm

4. Control parameter optimization process and results

4.1 Low-speed state control characteristics of the seat

There are many multi-modal control parameters for a certain type of seat. Due to practical engineering limitations, not all parameters can be adjusted, and the parameters that can be adjusted and optimized have different effects on the ejection and life-saving performance of the seat. Analyze the influence on the minimum safety height of the seat through deflecting control parameters, we can know that the control mode division threshold has a greater influence on the lifesaving performance of the seat, so they are used as the object for optimization simulation.

The seat adopts multi-modal control technology, the control method is complicated, and the number of control parameters is relatively large. After the ejection starts, the seat program controller selects the corresponding control mode to adjust the seat attitude according to the flight state parameters provided by the inertial navigation. When the seat is ejected in a low-speed flight state, the division of the control mode is mainly determined by the following 6 boundary thresholds:

$$V_{up} = -40m/s$$
$$|\theta_f| = 60^\circ$$
$$|\gamma + 0.2\omega_x| = 120^\circ$$
$$|\gamma + 0.2\omega_x| = 80^\circ$$
$$|\gamma + 0.2\omega_x| = 30^\circ$$
$$V = 150km/h$$

The control mode division rule determined by these 6 boundary thresholds is shown in Figure 2.

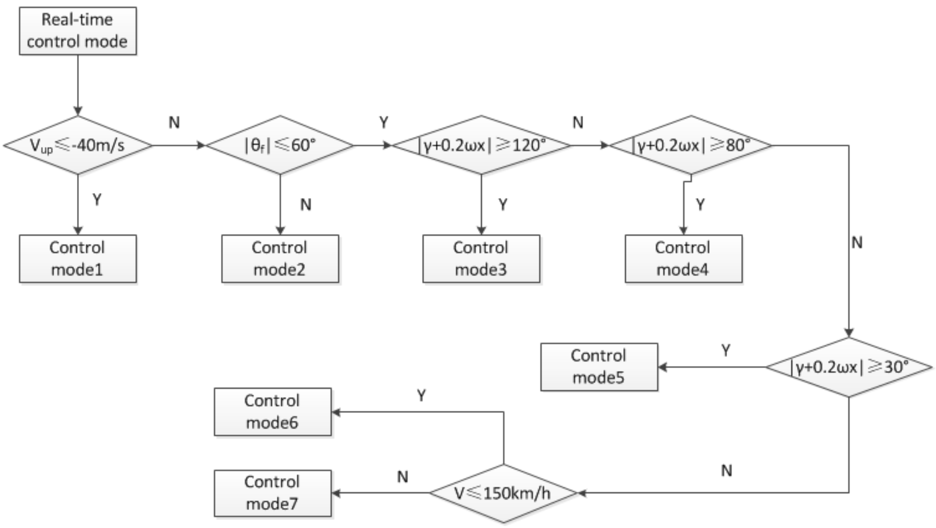

Figure 2 Division rules of seat control modes at low speed

Under the modal division rules shown in Figure 2, the simulation calculation results of the prototype seat's minimum safety height under the NMS 88 low-speed conditions are shown in Table 1. Since the typical state of the NMS does not specify the roll angular velocity, the initial value of the roll angular velocity is 0 when the seat is simulated. There are 44 states in the 88 low-speed states that meet the NMS. It can be seen that the states that do not meet the requirements of the NMS are mainly concentrated in the state of large sinking rate, large dive angle and large roll angle.

4.2 Preliminary optimization results

The particle swarm optimization algorithm is used to optimize the simulation analysis of 6 thresholds. The fitness function is N. The operating parameters of the optimization algorithm are: inertia factor $w=0.6$; acceleration constant $c_1=c_2=2$; particle swarm size is 20; the maximum number of iterations is 20; the maximum velocity of the particle is $V_{\max}=1$; the fitness value is 88.

After the calculation is completed, the optimization results of the 6 thresholds are as follows:

$$V_{\mathrm{up}}=-44.5m/s$$
$$|\theta_{\mathrm{f}}|=53.4^{\circ}$$
$$|\gamma+0.2\omega_x|=111.8^{\circ}$$
$$|\gamma+0.2\omega_x|=72.9^{\circ}$$
$$|\gamma+0.2\omega_x|=34.7^{\circ}$$
$$V=258.8km/h$$

The simulation results of the lowest safety height under this set of parameters are shown in Table 1:

Table 1 Simulation results of the lowest safety height after initial optimization

Aircraft conditions			Minimum Safety Altitude (m)											
Indicated airspeed (km/h)	Dive angle (°)	Sink rate (m/s)	Roll Angle During Flight											
			0°			45°			90°			180°		
			Std.	Val1	Val2	Std.	Val1	Val2	Std.	Val1	Val2	Std.	Val1	Val2
0	0	0	0	0	0	0	0	0	6	0	0	52	66*	66*
		10	0	0	0	0	0	0	21	19	19	61	76*	76*
		30	24	49*	49*	27	39*	39*	49	61*	61*	79	99*	99*
		50	52	78*	78*	53	79*	78*	67	85*	85*	91	95*	95*
250	0	0	0	0	0	0	0	0	3	0	0	37	29	29
		10	0	0	0	0	0	0	9	5	5	49	41	41
		30	9	21*	13*	12	17*	17*	34	36*	36*	64	63	63
		50	34	58*	58*	37	59*	59*	55	68*	68*	82	82	82
450	0	0	0	0	0	0	0	0	3	0	0	27	18	18
		10	0	0	0	0	0	0	6	4	4	34	29	29
		30	3	14*	14 *	6	13*	13*	31	27	27	55	49	49
		50	27	45*	45*	34	47*	47*	49	54*	54*	70	69	69
100	20	V_Z	0	0	0	0	0	0	21	9	9	58	73*	73*
0	30	V_Z	0	0	0	0	0	0	15	0	0	52	60*	60*
	60		0	0	0	6	0	0	21	0	6	40	48*	36
	90		24	4	4	24	4	4	24	4	4	24	4	4
250	30	V_Z	24	27*	20	27	23	23	46	42	42	70	68	68
	60		64	77*	77*	67	84*	84*	76	100*	100*	88	92*	92*
	90		85	95*	95*	85	95*	95*	85	95*	95*	85	95*	95*
450	30	V_Z	40	59*	59*	46	62*	62*	61	68*	68*	82	80	80
	60		91	109*	109*	95	118*	118*	101	129*	129*	116	121*	121*
	90		119	131*	131*	119	131*	131*	119	131*	131.0*	119	131*	131*

Note 1：The val1 in the table represents the original data, while the val2 represents the optimized data.
Note 2：The values marked with "*" in Table are more than those required by NMS.
Note 3：The blue values in Table 1 are less than those of original data, while the red values in Table 1 are more than those of original data

It can be seen from Table 1 that a total of 46 of the 88 low-speed states meet the requirements of the NMS. There are two more states on the basis of the prototype seat, namely state one with 0km/h speed, 60° dive angle, 0m/s sinking rate, and 180° roll angle is; and state two with 250km/h speed, 30° dive angle, 0m/s sinking rate , and 0°roll angle. The control mode of the first state is changed from the control mode 3 to the control mode 2, and the control mode of the second state is changed from the control mode 7 to the control mode 6.

The optimization results show that after the optimization of the control mode division threshold, the control mode of the seat has changed in some states, which improves the performance of the seat to a certain extent.

4.3 Iterative optimization results

The 6 thresholds of the division modes have been optimized for many times, and it is found that 46 of the 88 low-speed states of the NMS are met at most. However, the difference between the minimum safety height values corresponding to the multiple sets of thresholds that meet the 46 states is different from the original state. In order to further analyze the impact of the six thresholds on the seat performance, this paper compares and analyzes the minimum safe height values before and after optimization. The increase in the minimum safety height value after optimization results in poor performance. Among the 88 states, the number of states where the performance has deteriorated after optimization is recorded as X; otherwise, it means better performance, and the number of states is recorded as Y. This paper uses the evaluation value M and the degree of improvement P to measure the performance improvement effect of the minimum safety height of the seat after parameter optimization:

$$M = Y - X \tag{4}$$

$$P = \frac{M}{88} \times 100\% \tag{5}$$

The greater the evaluation value M, the better the seat performance under this parameter. Therefore, evaluation value M can be used as the fitness function. Then, using the number of states meeting the NMS $N \geq 46$ as the constraint condition, the 6 division thresholds are further optimized. The operating parameters of the optimization algorithm are still set as described above: inertia factor $w = 0.6$; acceleration constant $c_1 = c_2 = 2$; particle swarm size is 20; the maximum number of iterations is 20; the maximum velocity of the particle is $V_{max} = 1$; the fitness value is 88

After the calculation is completed, the optimization results of the 6 thresholds are as follows:

$$\begin{aligned}
&V_{up} = -65.1m/s \\
&|\theta_f| = 54.2^{o} \\
&|\gamma + 0.2\omega_x| = 136.4^{o} \\
&|\gamma + 0.2\omega_x| = 85.2^{o} \\
&|\gamma + 0.2\omega_x| = 26.7^{o} \\
&V = 259.2km/h
\end{aligned}$$

The simulation results of the minimum safety height corresponding to the seat under this set of parameters are shown in Table 2. From the table, it can be seen that the number of states among 88 low-speed states that meet the NMS is 46, and the corresponding evaluation value is $M = 11$, degree of performance improvement relative to the prototype seat is $P = 12.5\%$.

Table 2 Simulation results of the lowest safety height after Iterative optimization

Aircraft conditions			Minimum Safety Altitude (m)											
Indicated airspeed (km/h)	Dive angle (°)	Sink rate (m/s)	Roll Angle During Flight											
			0°			45°			90°			180°		
			Std.	Val1	Val2	Std.	Val1	Val2	Std.	Val1	Val2	Std.	Val1	Val2
0	0	0	0	0	0	0	0	0	6	0	0	52	66*	66*
		10	0	0	0	0	0	0	21	19	19	61	76*	76*
		30	24	49*	49*	27	39*	39*	49	61*	61*	79	99*	99*
		50	52	78*	72*	53	79*	75*	67	85*	84*	91	95*	132*
250	0	0	0	0	0	0	0	0	3	0	0	37	29	29
		10	0	0	0	0	0	0	9	5	5	49	41	41
		30	9	21*	13*	12	17*	17*	34	36*	36*	64	63	63
		50	34	58*	44*	37	59*	46*	55	68*	63*	82	82	82
450	0	0	0	0	0	0	0	0	3	0	0	27	18	18
		10	0	0	0	0	0	0	6	4	4	34	29	29
		30	3	14*	14*	6	13*	13*	31	27	27	55	49	49
		50	27	45*	37*	34	47*	38*	49	54*	56*	70	69	69
100	20	V_z	0	0	0	0	0	0	21	9	9	58	73*	73*
0	30	V_z	0	0	0	0	0.0	0	15	0	0	52	60*	60*
	60		0	0	0	6	0.0	0	21	0	6	40	48*	36
	90		24	4	4	24	4	4	24	4	4	24	4	4
250	30	V_z	24	27*	20	27	23	23	46	42	42	70	68	68
	60		64	77*	65*	67	84*	71*	76	100*	89*	88	92*	112*
	90		85	95*	95*	85	95*	95*	85	95*	95*	85	95*	95*
450	30	V_z	40	59*	52*	46	62*	52*	61	68*	70*	82	80	80
	60		91	109*	109*	95	118*	118*	101	129*	129*	116	121*	121*
	90		119	131*	131*	119	131*	131*	119	131*	131*	119	131*	131*

Note 1：The val1 in the table represents the original data, while the val2 represents the optimized data.
Note 2：The values marked with "*" in Table 1 are more than those required by NMS.
Note 3：The blue values in Table are less than those of original data, while the red values in Table 1 are more than those of original data

5. Conclusion

In this paper, the control parameters of a certain type of seat have been simulated and optimized. Through the comparison and analysis of the minimum safety height of 88 low-speed states in the NMS and the minimum safety height of the prototype seat, the iterative optimization of the control parameters has been completed . The optimization results show that after optimizing the control parameters, the life-saving performance of the seat has been improved. Two unsatisfied states of the prototype seat have been satisfied, and among 88 states, the number of states thate the minimum safety height of the seat is better than that of the prototype seat is 11, which is an increase of 12.5% on the basis of the prototype seat, and verifies the credibility and effectiveness of the particle swarm optimization method.

6. Copyright Statement

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