The Comparison Discussion on the Controlling Effect of Parasitic Accelerations Generated by Human Centrifuge by Different Controlling Methods

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Abstract. When simulating acceleration of pure Gz direction, when precision requirement of centrifuge Gz direction is provided, the max values of parasitic accelerations permitted to occur in other directions such as Gx, Gy directions are also provided in the meantime. The research is on account of motion pattern of three axial human centrifuge, introduces Euler recursion method and trapezoid method, designs computer simulations of different smoothing number of times and smoothing time on account of Euler recursion method and trapezoid method and compares simulation results, that is the controlling effects of parasitic accelerations generated by human centrifuge when making the simulation of pure Gz by the two controlling methods. Result shows: the two methods both can restrain the values of parasitic accelerations of x and y directions with effect, and to rque demanded by system decreases after smoothing acceleration curves. Compared to Euler method, the computing amount of trapezoid method is larger, while the eliminating effect for parasitic accelerations is better, and it makes computing accuracy of result be higher. The study result can be as the important reference resource when selecting and researching controlling methods of the parasitic accelerations generated by human centrifuge.

1. Introduction
The imitation of pure Gz acceleration is all along one of the major imitation items of human centrifuge. When on human centrifuge with three-axis, subject is suffered accelerations of x, y and z, three directions. In the meantime, the subject is also suffered to gravity accelerations Gt, Gr, Gv coming from tangential, radial and longitudinal, and the resultant acceleration of them is called Gr. Since roll and pitch movements of cockpit can not enable acceleration of Gz direction go after entirely the synthetic vector of acceleration, acceleration of Gr direction which is generated in running of human centrifuge, so it brings out that the projection compositions in Gx and Gy directions are generated, namely the parasitic accelerations. In actual apply, parasitic acceleration should be controlled to get minimum or removed as much as possible, to decrease the negative effect brought by them, such as making pilot generate misconception, even aggravating misconception produced Coriolis force. For centrifuge which has cabinet system of single free degree, it is impossible to remove, decrease or control with effect the generation of linear acceleration in other direction, but for human centrifuge which has complex cabinet system, roll and pitch motion of cabinet may weaken the affects of acceleration in other directions, or limit them to a very low standard. So when formulating the
precision requisition of G load for such kind of human centrifuge, the values of accelerations permitted to occur in other directions should also be formulated in the meantime[1][2].

So far, there exit mainly two methods to decrease parasitic acceleration. One method is to raise the capacity of roll and pitch motions, that is speeding up the motion velocity of roll and pitch. But it will add system scale and power export, primarily adding the irritate of flyer's angular movement. So, it is not usually to seek exorbitant roll and pitch motion capability in actual apply [3]. Another way is to slow down the variation velocity of the synthetic vector direction, namely to slow down the resultant acceleration Gr, which can obtain the similar effect as well. While this kind of method requires completing aim at the expense of a certain response time. However, the adverse affect of this way is correspondingly smaller, and if it is contrasted with the first way which is increasing the motion capability of pitch and roll, this way will not cause the subject to produce the more uncomfortable feel and is more easily to be received. A lot of researchers carry on much relative research round human centrifuge and its all kinds of computation of angular velocity and so forth [4-6]. This research is similar to the second way. Through devising the smoothing transiting section in front part of acceleration profile, computer simulating with different smoothing number of times and smoothing time is devised, and the values of Gx and Gy before and after making smoothing which is on account of Euler method and trapezoid method are conducted comparison. The torque variation after making smoothing is discussed. It puts forward that torque variation should be as well the significant substance which ought to be followed with interest and considered when regulating the acceleration variation. The merit and demerit of Euler method and trapezoid method are also made a discussion.

2. The Establish of Movement Model of Human Centrifuge with Three Axis

On the basis of the movement disciplinarian when centrifuge makes motion in three axis directions, the suffered accelerations for subject in three directions of x, y, z are separately Gx, Gy, and Gz. The suffered accelerations for subject in tangential, radial and direction of gravity are separately GT, GR, and GV, and the resultant acceleration, namely the synthesized acceleration is called Gr[2]. And supposing that length size of major arm of human centrifuge is expressed by R, angular speed of major arm is expressed by \(\omega\), angular acceleration is expressed by \(\omega^2\), and angle of rotation of pitch axis is expressed by \(\theta\), angle of rotation of roll axis is expressed by \(\phi\), and the existing a coincidence relationship among various of accelerations is in the formulas which are as the following:

\[
\begin{align*}
G_T & = \left( w R \right) / g \\
G_R & = \left( w^2 R \right) / g \\
G_r & = g / g = 1 \\
G_r^2 & = G_T^2 + G_R^2 + G_\theta^2 \\
G_{rv} & = \sqrt{G_R^2 + G_V^2} \\
G_{xz} & = \sqrt{G_x^2 + G_z^2}
\end{align*}
\]

Inside the formula, GRV is the synthesized acceleration of accelerations GR and GV. GXZ is the synthesized acceleration of accelerations Gx and Gz. Thus angle of rotation of pitch axis is expressed by \(\theta\), angle of rotation of roll axis is expressed by \(\phi\), and the existing a coincidence relationship among various of accelerations is in the formulas which are as the following:

\[
\begin{align*}
\phi & = \arcsin \frac{G_T}{G_{rv}} \pm \arcsin \frac{G_x}{G_{rv}} \\
\theta & = \arcsin \frac{G_r}{G_{xz}} \mp \arcsin \frac{G_x}{G_{xz}}
\end{align*}
\]
When making simulation of pure Gz, accelerations of Gx and Gy are both considered to be zero, and it is thought that Gz = Gr, thus formula (5) and (6) may be made simplification as the formula (7) and (8) which are as the following:

\[ \varphi = \arcsin \frac{G_R}{G_{RV}} \quad (7) \]

\[ \theta = \arcsin \frac{G_r}{G_r} \quad (8) \]

On account of the input objective parameter Gz, the angular speed of major arm, that is \( \omega \) can be computed, and on account of the upper formulas, the built motion profile and motion regular of each parameter can be computed, and they may be used as value of motion of each axis for reference, namely the setting value. Motions of three axis of centrifuge are regulated by regulator of each axis, and then overload G value and each acceleration value which are actually output can be acquired.

Supposing that centrifuge gets baseline of 1.41G at a certain speed, then after having a residence for several seconds at baseline, reaching the setting G value at the onset rate of acceleration which is 6G/s, and the value of acceleration before smooth may be shown using the following formula:

\[ G_z = 6t + 1.41 \quad (9) \]

Designing continuous smoothing transition section of different number of times and different smoothing transition time, then Gz needs satisfy the initial requirement of baseline, namely when satisfying \( t \) is equal to 0, Gz is equal to 1.41, and at the moment of transition time finishes, the subsection function should have the same value. So the subsection expression of Gz can be got.

\[ \begin{cases} \varphi_q = 4t^2 + \pi/4 \\ \theta_q = 7.5t^2 \end{cases} \quad (10) \]

The generated parasitic acceleration can be expressed by using the following formula:

\[ \begin{cases} G_y = G_r \sin(\varphi - \varphi_q) \\ G_x = G_r \sin(\theta - \theta_q) \end{cases} \quad (11) \]

The transition section of smoothing is designed at the front segment of acceleration graph. In this research, Euler method and trapezoid method in numerical integration methods are selected and used to devise computer simulating of different smooth time number and smooth time on the basis of this two methods. Based on a sequence of calculation formulas, angle \( \theta \) of rotation of pitching axis, and angle \( \varphi \) of rotation of rolling axis before and after smooth are acquired, then Gx, Gy, the parasitic accelerations before and after smooth are acquired, and Gx, Gy, the parasitic accelerations before and after smooth are made a comparison, at the same time, the two methods are made a discussion.

3. The Brief Introduction of Numerical Integration Method [7]

3.1. Euler Method

Euler method is the simplest single step way, which is with one order, with poor precision, simple formula and this method has obvious geometric significance. Its recurrence equation is as the following:

\[ \frac{dy}{dt} = f(t, y) \quad y(t_0) = y_0 \quad (12) \]

Considering the original value issue, for the original value issue shown in the above formula, the solution of it is the effect of a successive variable t, and if it is substituted with a sequence of the approximation value \( y(t_1), y(t_2), \ldots, y(t_n) \) at discrete moment, among this, \( y(t_i) = t_0 + ih \), step
length is expressed with h, which is the range between two contiguous points. Supposing that equation (12) is made integration in the interval \((t_i, t_{i+1})\), it can be got that:

\[
y(t_{i+1}) - y(t_i) = \int_{t_i}^{t_{i+1}} f(t, y) \, dt
\]  

(13)

In general, it has very big difficulty to discover the integral of the right side in the upper formula. Its geometrical significance is the area of graph \(f(t, y)\) in the interval \((t_i, t_{i+1})\), and when \((t_i, t_{i+1})\) is sufficiently small, it can be approximately replaced by rectangular area.

\[
\int_{t_i}^{t_{i+1}} f(t, y) \, dt = hf(t, y(t_i))
\]  

(14)

Therefore, equation (13) can be approximately as the following:

\[
y(t_{i+1}) = y(t_i) + hf(t_i, y(t_i))
\]  

(15)

Its written recursion is as:

\[
y(t_{i+1}) = y(t_i) + hf(t_i, y(t_i)), \quad n=0, 1, 2, \ldots, N
\]  

(16)

If it is known that \(y(0) = y_0\), \(y(t_i)\), \(y(t_{i+1})\) can be found from the above formula, and so on, from the value \(y(t_i)\) of the previous point \(t_i\), the value \(y(t_{i+1})\) of the later point \(t_{i+1}\) can be got. This algorithm is called the single step method. Because equation (16) can directly take the known initial value \(y_0\) in equation (12) as the initial value when making recursive calculation, and not need other information, the single step method is a kind of self starting algorithm.

3.2. Trapezoid Method

Trapezoid method is also an improved Euler method. For the integral formula (13), by calculating the right end integral using trapezoid area formula, it can be got that:

\[
y(t_{i+1}) = y(t_i) + \frac{h}{2} \left[ f(t_i, y(t_i)) + f(t_{i+1}, y(t_{i+1})) \right]
\]  

(17)

The above formula is written as recursive difference format which is as the following:

\[
y(t_{n+1}) = y(t_n) + \frac{h}{2} (f_n + f_{n+1})
\]  

(18)

It can be seen that from the above equation (18), when calculating equation (12) using trapezoid method, \(f_{n+1}\) is needed to know in computation of \(y_{n+1}\), while \(f_{n+1} = f(t_{n+1}, y_{n+1})\) depends on \(y_{n+1}\) itself. Therefore, each estimated \(y^{p}_{n+1}\) is firstly calculated by using Euler method, and then the value is substituted into the original equation (12) to calculate \(f^{p}_{n+1}\), and finally the modified \(y^{c}_{n+1}\) is found by using equation (18). So the improved Euler method can be described as:

Forecast: \(y^{p}_{n+1} = y_n + hf(t_n, y_n)\)

(19)

Correcting: \(y^{c}_{n+1} = y_n + \frac{h}{2} \left[ f(t_n, y_n) + f^{p}(t_{n+1}, y^{p}_{n+1}) \right] \quad n = 0, 1, 2, \ldots\)

(20)

Euler method only needs call \(f\) once for each calculation step, while the improved Euler method has twice the calculation amount compared with Euler method due to the addition of correction process, so as to improve the calculation accuracy.
4. Results and Discussions
The computer simulating with different times number of smoothing and smoothing time is performed by using Euler method and trapezoidal method, and the parasitic accelerations which are in x and y directions before and after smoothing with different times number of smoothing and smoothing time are obtained. A sequence of figures is drawn and made contrast and analyzes. The Figure 1 which is in the following is the comparison figure of parasitic accelerations in Gx and Gy directions by using Euler method when smoothing time takes 0.2s and smoothing times number takes 3 times before and after smoothing. The Figure 2 which is in the following is the comparison figure of parasitic accelerations in Gx and Gy directions by using trapezoidal method when smoothing time takes 0.2s and smoothing times number takes 3 times before and after smoothing. The Figure 3 in the following is the comparison figure of parasitic accelerations in Gx and Gy directions by using Euler method when smoothing time takes 0.3s and smoothing times number takes 4 times before and after smoothing. The Figure 4 in the following is the comparison figure of parasitic accelerations in Gx and Gy directions by using trapezoidal method when smoothing time takes 0.3s and smoothing times number takes 4 times before and after smoothing.

**Figure 1.** The comparison figure of parasitic accelerations Gx and Gy by using Euler method when smoothing time takes 0.2s and smoothing times number takes 3 times before and after smoothing

**Figure 2.** The comparison figure of the parasitic accelerations Gx and Gy by using trapezoidal method when smoothing time takes 0.2s and smoothing times number takes 3 times before and after smoothing
Figure 3. The comparison figure of the parasitic accelerations Gx and Gy by using Euler method when smoothing time takes 0.3s and smoothing times number takes 4 times before and after smoothing.

Figure 4. The comparison figure of the parasitic accelerations Gx and Gy by using trapezoid method when smoothing time takes 0.3s and smoothing times number takes 4 times before and after smoothing.

It may be known from the figures that the curves show clear changes before and after smoothing, no matter Eulerian method or trapezoid method, namely the parasitic accelerations in x and y directions have been controlled nicely. It can be known from a lot of figures that the smoothing effect gets up and up with raising of time t, and the smoothing effect gets up and up with raising of times number of smoothing. It may be known from a lot of curves that, the effect of smoothing is not ideal if the smoothing time t is extremely small. But if it is extremely big, the startup time will be extended, which is inconsistent with the demand of startup which requires safety and fast speed. Therefore, a suitable smoothing time t should be found by comprehensively considering. How to choose the appropriate time t is also an important issue which needs to be considered when controlling the parasitic accelerations. Comparing the comparison figures of Gx and Gy for Euler method and trapezoidal
method, it can be seen that curve change is more obvious by trapezoidal method than that of Euler method, and after smoothing the numerical values of Gx and Gy are smaller, that is, the control effect for curve is better, but the calculation amount and calculation time of trapezoidal method will be relatively longer. In addition, by calculating angular speed of main arm w and angular acceleration dw, it is found that the angular acceleration dw after smoothing is reduced, and the less the times number of smoothing, the reduction is more. While parameter N and parameter dw are proportional, namely the torque of motor after smoothing is reduced as well. So it should be noted that the devised raising of smoothing part has an affect on torque which system outputs.

Compared with Euler method, trapezoid method takes value of the present point as the original value, takes average of derivative of the present point with derivative of the point at the next step as the derivative, and calculates the value of the point at the next step, but it needs to apply the value of the next point which is the latest to compute the derivative, iterating up to convergence. Because the trapezoid method synthesizes the derivative of two points, the calculated solution value is not much different from the exact solution value. Each calculation step of Euler method only needs to call f once, while the improved Euler method, that is trapezoid method, adds the correction process, so the trapezoid method has higher accuracy, but the calculation amount is double of that of Euler method, and the calculation time is also longer. It should be noted that the research in this study is simulation research, that is to say, it is thought that it is performed under perfect conditions of simulating, while actually, in actual apply, the parasitic acceleration and some other parameters are influenced as well by various of elements, for example, response time of driving, control features and response features of rolling and pitching motors, so the simulation results are only as a significant reference foundation for research. In this study, the method of piecewise smoothing is used, and the Euler method and trapezoid method are used when parameter is recursive, and is made a compared. This is a common numerical integration method in system simulation. Besides, there exit other recursion methods, for example, Runge Kutta method, Euler midpoint method and others. Runge Kutta method also includes first-order Runge Kutta method, second-order Runge Kutta method, third-order Runge Kutta method and fourth-order Runge Kutta method. Euler method is a kind of first-order one-step way which is got by y(t_n + h), which is that \( y = f(t, y) \), \( y(t_1) = y(0) \) is near point \( t_n \), is expanded by Taylor series and is cut off all items after \( h^2 \), so its accuracy is lower.

If the expansion:

\[
y(t_n + h) = y(t_n) + h f(t_n, y_n) + \frac{h^2}{2!} f'(t_n, y_n) + \cdots
\]  \hspace{2cm} (21)

is cut off after more several terms are taken, a higher-order numerical solution with higher accuracy can be obtained, but higher derivative of the function is needed to be calculated if Taylor expansion is used directly. The Runge Kutta method uses the idea of indirectly using Taylor expansion, that is the linear combination of the function value f at n points is used to replace the derivative of f, then the coefficient among them is determined according to the Taylor expansion to improve the order of algorithm. In this way, not only the derivative of function can be avoided to calculate, but also the calculation accuracy can be guaranteed [7]. Because Runge Kutta method has many advantages, it is one of the most basic algorithms in many simulation packages. Therefore, compared with Euler method, trapezoid method has more high accuracy in approximation of numerical value, and is hoped to get superior results.

The above mentioned numerical solution mentions are all single-step methods, that is, according to the initial conditions, the y values of successive all moments can be calculated recursively, so this method can start automatically. In addition, another kind of algorithm, linear multistep, i.e. multistep method, can be used. When using this kind of algorithm to solve problems, it may be necessary to use y and value of \( f(t, y) \) at the each moment of \( t_n \), \( t_{n-1} \), \( t_{n-2} \), ... . In obviously, the calculation formula of multi-step method can't start automatically and takes up a large amount of memory in the calculation process. But it can improve the accuracy and speed. Among this, method of multi-step also includes Adams bezihos clear multi-step way (Adams method for short) and Adams Morton implicit multi-step way, Adams bezihos clear multi-step way is to use an interpolation polynomial to approximately
substitute \( f(t,y(t)) \), and on the nodes with \( k \) number before \( t_n \) point, \( f(t,y(t)) \) is expressed approximately with polynomial, among which \( K \) is called polynomial order number. \( n_y, n_f, 1-n_f, 2-n_f \). If at \( t_n \) point, \( y_n, f_n, f_{n-1}, f_{n-2} \) are already known at the point, then the value of \( y_{n+1} \) obtained later is the linear combination of the derivatives before step \( k-1 \), and each derivative appears \( y(t_{n+1}) \) in explicit form, so it is called explicit linear multistep method. According to the interpolation theory, it can be got that the selection of interpolation nodes has a direct impact on the accuracy, and the interpolation formula with the same order is more accurate than the extrapolation formula. Newton forward interpolation formula is used to replace approximately \( f(t,y(t)) \) in equation (13), and the calculation formula of Adams Morton implicit multi-step method can be obtained by imitating the derivation process of explicit multi-step method. If the explicit formula and the implicit formula of Adams method is jointly used, the former provides the predicted value, and the latter corrects the predicted value to make it more accurate, and this is the prediction correction method, which can make the calculation result more accurate [7]. In addition, in control method, there are also optimal control methods [8-10] and other methods that can be selected, and other digital filters can be used to make filtering and smoothing treatment for curve [11] [12]. By the comparison of different numerical solution methods, this research aims to lead more and better ways and thoughts, which can be more tried and probed in coming research. The controlling issue of the parasitic accelerations for \( x \) and \( y \) directions when making simulation of pure \( Gz \), is always an inevitable issue in the devise of human centrifuge system. It is thought that with the continual rapid growth with leap of current controlling theoretic and computer technique, such issue can also find much better disposition methods.

5. Conclusions

On account of the established movement pattern of the human centrifuge of three-axis, this study designs calculator simulations of different times number of smoothing and time of smoothing on account of Euler recurrence way and trapezoid method, and the results of simulating of the two methods are contrasted. The results express the two methods can both effectually restrain magnitude of parasitic accelerations of \( x \) and \( y \) directions. With raising of time \( t \) and raising of times number for smoothing, the effect of smoothing of both methods tends to become better. While in actual apply, the appropriate smoothing time \( t \) should be considered comprehensively to research. The comparison results show that trapezoid method changes the curve more obviously than Euler method, and the values of \( Gx \) and \( Gy \) are smaller after smoothing, that is, the control effect for curve is better, and the accuracy of trapezoid method is higher, but the calculation amount and calculation time are also longer. The comparison results are explained from the control theory and control principle. Smooth processing affects the change of output torque. Euler method and trapezoid method reduce the torque system requires after smoothing. Different control methods have different effects on the torque system outputs, that is the corresponding required input torque which system needs, i.e. whether the needed torque is reduced or increased, which point should be fully considered when system is designed. This study introduces other good recursive methods such as Runge Kutta method. At the same time, the other algorithms, such as linear method of multi-step which includes Adams bezihos clear method of multi-step (Adams method for short) and Adams Morton implicit multi-step method, are made a brief introduction. The comparison result of this study may be used as ground of reference when the ways else to restrain parasitic acceleration are designed. It is considered that with continual rapid growth with leap of current controlling theoretic, controlling way and current computer technique, the control problem of parasitic acceleration on human centrifuge when making simulation of pure \( Gz \) can get more and more advanced, much better disposition and achievement.

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