

Control method of non-sinusoidal hydraulic vibration curve of mold

Technical Field:

The present disclosure belongs to the technical field of metallurgical continuous casting automation, and particularly relates to a method for controlling a non-sinusoidal hydraulic vibration curve of a mold.

Background Art:

High-efficiency continuous casting is a main development direction of modern continuous casting technology, and mainly includes high casting speed, high quality, high operating rate, and high-temperature hot charging, among which high casting speed is one of the main indicators of the development of modern continuous casting technology. However, high casting speed increases friction between a cast slab and a mold, thereby causing quality or production accidents such as cracking and breakout of the cast slab. Accordingly, on one hand, mold flux suitable for high-speed casting is added, and on the other hand, a mold vibration mode suitable for high-speed casting is adopted.

Non-sinusoidal vibration is a novel mold vibration technology developed for satisfying requirements of high-speed casting. In order to satisfy continuous casting production requirements, an ideal non-sinusoidal vibration curve waveform should have characteristics of low upward vibration speed, high downward vibration speed, short negative strip time, a continuous and smooth velocity curve, and stable acceleration variation. However, existing non-sinusoidal vibration modes still have problems such as abrupt acceleration variation, limited vibration skew ratio, and complex models.

In order to improve cast slab quality and reduce impact on equipment, a novel non-sinusoidal mold vibration mode is to be developed so as to improve vibration waveforms, improve production efficiency, and reduce production costs.

Summary of the Invention:

In view of the above, an objective of the present disclosure is to provide a method for controlling a non-sinusoidal hydraulic vibration curve of a mold. The method optimizes a non-sinusoidal vibration curve, realizes a stable and smooth hydraulic cylinder velocity curve with a small peak value and continuous, smooth, and non-abrupt acceleration variation, and has

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advantages of a simple control method, easy implementation, a small number of control parameters, and convenient operation.

In order to achieve the above objective, the present disclosure provides the following technical solution:

A method for controlling a non-sinusoidal hydraulic vibration curve of a mold adopts a three-stage linear-sinusoidal composite function, wherein one oscillation period of a position curve comprises three stages:

a first stage being a pseudo-sinusoidal curve obtained by superposition of a standard sinusoidal function with an angular frequency of ω_1 and a linear function having a slope of $-\frac{T_1}{2\pi}a(a-1)$;

a second stage being a pseudo-sinusoidal curve obtained by superposition of a standard sinusoidal function with an angular frequency of ω_2 and a linear function having a slope of $\frac{T_1^2}{2\pi} \frac{1-a}{T_2}$ and an offset value of $\frac{T_1^2}{4\pi} \frac{a^2-1}{a}$;

and a third stage being a pseudo-sinusoidal curve obtained by superposition of a standard sinusoidal function with an angular frequency of ω_1 and a linear function having a slope of $-\frac{T_1}{2\pi}a(a-1)$ and an offset value of $-\frac{T_1^2}{2\pi}a(a^2-1)$, wherein the third stage is connected to the pseudo-sinusoidal curve of the first stage at different sampling times.

According to a continuous cycle period, the function is a function formed by connecting pseudo-sinusoidal curves obtained through superposition and deformation of standard sinusoidal functions having angular frequencies respectively of ω_1 and ω_2 and linear functions having different slopes. The position curve equation of the non-sinusoidal hydraulic vibration curve is as follows:

$$f(t) = \begin{cases} -\frac{T_1}{2\pi} \left(\frac{T_1}{2\pi} \sin\left(\frac{2\pi}{T_1}t\right) + a(a-1)t \right), t \in (0, \frac{T_1}{2}) \\ \frac{T_1^2}{2\pi} \left(\frac{a}{2\pi} \sin\left(\frac{2\pi}{T_2}\left(t - \frac{T_1}{2}\right)\right) - \frac{a-1}{T_2}t + \frac{a^2-1}{2a} \right), t \in (\frac{T_1}{2}, \frac{T_1}{2} + T_2) \\ -\frac{T_1}{2\pi} \left(\frac{T_1}{2\pi} \sin\left(\frac{2\pi}{T_1}(t - T_2)\right) + a(a-1)(t + T_1(a+1)) \right), t \in (\frac{T_1}{2} + T_2, T_1 + T_2) \end{cases}$$

wherein ω_1 and ω_2 are angular frequencies of two standard sinusoidal functions respectively, corresponding oscillation periods are respectively T_1 and T_2 , in units of ms; t is a sampling time of

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the vibration curve, in units of ms; a is a steady rising time in the vibration curve, in units of ms; and $T_2 = aT_1$.

A vibration velocity curve equation for one period corresponding to the non-sinusoidal hydraulic vibration curve equation is as follows:

$$v(t) = \begin{cases} -\frac{T_1}{2\pi} \left(\cos\left(\frac{2\pi}{T_1}t\right) + a(a-1) \right), & t \in (0, \frac{T_1}{2}) \\ \frac{aT_1^2}{2\pi T_2} \left(\cos\left(\frac{2\pi}{T_2}(t - \frac{T_1}{2})\right) - \frac{a-1}{a} \right), & t \in (\frac{T_1}{2}, \frac{T_1}{2} + T_2) \\ -\frac{T_1}{2\pi} \left(\cos\left(\frac{2\pi}{T_1}(t - T_2)\right) + a(a-1) \right), & t \in (\frac{T_1}{2} + T_2, T_1 + T_2) \end{cases}$$

Therefore, according to the above vibration velocity curve equation and an extremum principle, times corresponding to a minimum vibration position and a maximum vibration position occurring within one period, namely times at which the vibration velocity is equal to 0, can be obtained. The times can be obtained by the following formulas:

$$\begin{cases} -\frac{T_1}{2\pi} \left(\cos\left(\frac{2\pi}{T_1}t_{\min}\right) + a(a-1) \right) = 0, & t_{\min} \in (0, \frac{T_1}{2}) \\ -\frac{T_1}{2\pi} \left(\cos\left(\frac{2\pi}{T_1}(t_{\max} - T_2)\right) + a(a-1) \right) = 0, & t_{\max} \in (\frac{T_1}{2} + T_2, T_1 + T_2) \end{cases}$$

wherein:

$$t_{\min} = \frac{-T_1 \arccos(a^2 - a)}{2\pi}, \quad t_{\max} = \frac{T_1(\pi + \arccos(a^2 - a))}{2\pi} + T_2;$$

wherein $t_{\min}$ is a time corresponding to the minimum vibration position within one period, in units of ms; and $t_{\max}$ is a time corresponding to the maximum vibration position within one period, in units of ms.

A vibration skew ratio is defined as a ratio of a difference between a time during which a slope of the vibration curve is positive and a time during which the slope of the vibration curve is negative within one oscillation period to the entire oscillation period. Therefore, the vibration skew ratio of the non-sinusoidal hydraulic vibration curve is calculated as follows:

$$s = \frac{2(t_{\max} - t_{\min}) - T}{T} * 100\% = \frac{\pi a + 2 \arccos(a^2 - a)}{(1 + a)\pi} * 100\%$$

wherein $T = T_1 + T_2$ is a oscillation period, in units of ms, and $a = \frac{T_2}{T_1}$;

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wherein, according to the above equation, the vibration skew ratio determining a waveform of the non-sinusoidal hydraulic vibration curve is related to oscillation period parameters T_1 and T_2 .

A vibration acceleration curve equation for one period corresponding to the non-sinusoidal hydraulic vibration curve equation is as follows:

$$\delta(t) = \begin{cases} \sin\left(\frac{2\pi}{T_1}t\right), t \in (0, \frac{T_1}{2}) \\ -\frac{1}{a}\sin\left(\frac{2\pi}{T_2}(t - \frac{T_1}{2})\right), t \in (\frac{T_1}{2}, \frac{T_1}{2} + T_2) \\ \sin\left(\frac{2\pi}{T_1}(t - T_2)\right), t \in (\frac{T_1}{2} + T_2, T_1 + T_2) \end{cases}$$

wherein, according to the above equation, the vibration acceleration curve is composed of three standard sinusoidal function segments connected at boundaries of respective intervals, and an acceleration variation of the vibration curve varies smoothly, such that the vibration acceleration curve is a continuous smooth curve without discontinuity.

Beneficial Effects of the Invention:

(1) The non-sinusoidal vibration curve formed by the three-stage linear-sinusoidal composite function has a relatively long rising time and a high descending speed, thereby effectively improving utilization of mold flux, enhancing a lubrication effect of the mold, and reducing breakout accidents. In addition, the non-sinusoidal vibration curve has stable and smooth vibration velocity and a reduced velocity peak value, and also ensures that variation of vibration acceleration is gentler, smooth, continuous, and non-abrupt, thereby causing relatively small impact and damage to equipment, being highly equipment-friendly, and effectively prolonging a service life of vibration equipment.

(2) The vibration control method implemented based on the above non-sinusoidal hydraulic vibration curve equation has simple parameter settings and may be changed according to any process value. Therefore, the above vibration waveform may be applied to slab, beam blank, and billet continuous casting machines, and has advantages of simple implementation, a wide application range, and strong practicability.

Other advantages, objectives, and features of the present disclosure will be set forth in part in the following description, and in part will be apparent to those skilled in the art based upon examination and study of the following description, or may be learned from practice of the present disclosure. The objectives and other advantages of the present disclosure may be realized and

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attained by the description set forth below.

Brief Description of the Drawings:

In order to make the objectives, technical solutions, and advantages of the present disclosure clearer, preferred detailed descriptions of the present disclosure are provided below in conjunction with the accompanying drawings, wherein:

FIG. 1 is a position curve of one oscillation period of a vibration method according to an embodiment of the present disclosure;

FIG. 2 is a vibration velocity curve of one oscillation period of a vibration method according to an embodiment of the present disclosure;

FIG. 3 is a vibration acceleration curve of one oscillation period of a vibration method according to an embodiment of the present disclosure;

FIG. 4 is a vibration curve of multiple oscillation periods of a vibration method according to an embodiment of the present disclosure;

FIG. 5 is position curves corresponding to different vibration skew ratios of a vibration method according to an embodiment of the present disclosure;

FIG. 6 is velocity curves corresponding to different vibration skew ratios of a vibration method according to an embodiment of the present disclosure;

FIG. 7 is acceleration curves corresponding to different vibration skew ratios of a vibration method according to an embodiment of the present disclosure.

Detailed Description of the Preferred Embodiments:

The following embodiments illustrate the implementation of the present invention through specific examples. Other advantages and effects of the invention can be readily understood by those skilled in the art based on the content disclosed in this specification. The invention may also be implemented or applied in other specific forms. The details disclosed herein may be modified or altered in various ways without departing from the spirit of the invention, depending on particular applications and interpretations. It should be noted that the drawings provided in the following embodiments are for illustrative purposes only and are intended to explain the basic concept of the invention. Where there is no conflict, the features of the embodiments may be combined with one another.

The drawings are intended for illustrative purposes only and are schematic rather than physical representations. They should not be construed as limiting the invention. Certain parts in the drawings may be omitted, enlarged, or reduced for clarity, and do not represent the actual size of the product. It is understood by those skilled in the art that some known structures and their descriptions may be omitted in the drawings.

Identical or similar reference numerals in the drawings of the embodiments correspond to identical or similar components. In the description of the present invention, it should be understood that positional or directional terms such as “upper”, “lower”, “left”, “right”, “front”, and “rear” are based on the orientations shown in the drawings. They are used merely for convenience of description and simplification, and are not intended to limit the structure or operation of the components to specific orientations. The actual meaning of such terms should be interpreted flexibly by those skilled in the art according to specific contexts.

Referring to FIGS. 1–7, the present disclosure provides a method for controlling a non-sinusoidal hydraulic vibration curve of a mold. A three-stage linear-sinusoidal composite function is adopted, wherein one oscillation period of a position curve comprises three stages. A first stage is a pseudo-sinusoidal curve obtained by superposition of a standard sinusoidal function having an angular frequency of ω_1 and a linear function having a slope of $\frac{T_1^2}{2\pi} \frac{1-a}{T_2}$. A second stage is a pseudo-sinusoidal curve obtained by superposition of a standard sinusoidal function having an angular frequency of ω_2 and a linear function having a slope of $\frac{T_1^2}{2\pi} \frac{1-a}{T_2}$ and an offset value of

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$\frac{T_1^2}{4\pi} \frac{a^2-1}{a}$. A third stage is a pseudo-sinusoidal curve obtained by superposition of a standard sinusoidal function having an angular frequency of ω_1 and a linear function having a slope of $-\frac{T_1}{2\pi}a(a-1)$ and an offset value of $-\frac{T_1^2}{2\pi}a(a^2-1)$, wherein the third stage is connected to the pseudo-sinusoidal curve of the first stage at different sampling times.

According to a continuous cycle period, the function is a function formed by connecting pseudo-sinusoidal curves obtained through superposition and deformation of standard sinusoidal functions having angular frequencies respectively of ω_1 and ω_2 and linear functions having different slopes. The position curve equation of the non-sinusoidal hydraulic vibration curve is as follows:

$$f(t) = \begin{cases} -\frac{T_1}{2\pi} \left(\frac{T_1}{2\pi} \sin \left(\frac{2\pi}{T_1} t \right) + a(a-1)t \right), t \in (0, \frac{T_1}{2}) \\ \frac{T_1^2}{2\pi} \left(\frac{a}{2\pi} \sin \left(\frac{2\pi}{T_2} \left(t - \frac{T_1}{2} \right) \right) - \frac{a-1}{T_2} t + \frac{a^2-1}{2a} \right), t \in (\frac{T_1}{2}, \frac{T_1}{2} + T_2) \\ -\frac{T_1}{2\pi} \left(\frac{T_1}{2\pi} \sin \left(\frac{2\pi}{T_1} (t - T_2) \right) + a(a-1)(t + T_1(a+1)) \right), t \in (\frac{T_1}{2} + T_2, T_1 + T_2) \end{cases}$$

wherein ω_1 and ω_2 are angular frequencies of two standard sinusoidal functions respectively, corresponding oscillation periods are respectively T_1 and T_2 , in units of ms; t is a sampling time of the vibration curve, in units of ms; a is a steady rising time in the vibration curve, in units of ms; and $T_2 = aT_1$.

A vibration velocity curve equation for one period corresponding to the non-sinusoidal hydraulic vibration curve equation is as follows:

$$v(t) = \begin{cases} -\frac{T_1}{2\pi} \left(\cos \left(\frac{2\pi}{T_1} t \right) + a(a-1) \right), t \in (0, \frac{T_1}{2}) \\ \frac{aT_1^2}{2\pi T_2} \left(\cos \left(\frac{2\pi}{T_2} \left(t - \frac{T_1}{2} \right) \right) - \frac{a-1}{a} \right), t \in (\frac{T_1}{2}, \frac{T_1}{2} + T_2) \\ -\frac{T_1}{2\pi} \left(\cos \left(\frac{2\pi}{T_1} (t - T_2) \right) + a(a-1) \right), t \in (\frac{T_1}{2} + T_2, T_1 + T_2) \end{cases}$$

Therefore, according to the above vibration velocity curve equation and an extremum principle, times corresponding to a minimum vibration position and a maximum vibration position occurring within one period, namely times at which the vibration velocity is equal to 0, can be obtained. The times can be obtained by the following formulas:

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$$\begin{cases} -\frac{T_1}{2\pi}(\cos(\frac{2\pi}{T_1}t_{\min}) + a(a-1)) = 0, t_{\min} \in (0, \frac{T_1}{2}) \\ -\frac{T_1}{2\pi}(\cos(\frac{2\pi}{T_1}(t_{\max} - T_2)) + a(a-1)) = 0, t_{\max} \in (\frac{T_1}{2} + T_2, T_1 + T_2) \end{cases}$$

wherein:

$$t_{\min} = \frac{-T_1 \arccos(a^2 - a)}{2\pi}, \quad t_{\max} = \frac{T_1(\pi + \arccos(a^2 - a))}{2\pi} + T_2;$$

wherein $t_{\min}$ is a time corresponding to the minimum vibration position within one period, in units of ms; and $t_{\max}$ is a time corresponding to the maximum vibration position within one period, in units of ms.

A vibration skew ratio is defined as a ratio of a difference between a time during which a slope of the vibration curve is positive and a time during which the slope of the vibration curve is negative within one oscillation period to the entire oscillation period. Therefore, the vibration skew ratio of the non-sinusoidal hydraulic vibration curve is calculated as follows:

$$s = \frac{2(t_{\max} - t_{\min}) - T}{T} * 100\% = \frac{\pi a + 2 \arccos(a^2 - a)}{(1 + a)\pi} * 100\%$$

wherein $T = T_1 + T_2$ is a oscillation period, in units of ms, and $a = \frac{T_2}{T_1}$;

wherein, according to the above equation, the vibration skew ratio determining a waveform of the non-sinusoidal hydraulic vibration curve is related to oscillation period parameters T_1 and T_2 .

A vibration acceleration curve equation for one period corresponding to the non-sinusoidal hydraulic vibration curve equation is as follows:

$$\delta(t) = \begin{cases} \sin(\frac{2\pi}{T_1}t), t \in (0, \frac{T_1}{2}) \\ -\frac{1}{a} \sin(\frac{2\pi}{T_2}(t - \frac{T_1}{2})), t \in (\frac{T_1}{2}, \frac{T_1}{2} + T_2) \\ \sin(\frac{2\pi}{T_1}(t - T_2)), t \in (\frac{T_1}{2} + T_2, T_1 + T_2) \end{cases}$$

wherein, according to the above equation, the vibration acceleration curve is composed of three standard sinusoidal function segments connected at boundaries of respective intervals, and an acceleration variation of the vibration curve varies smoothly, such that the vibration acceleration curve is a continuous smooth curve without discontinuity.

In the present embodiment, specific implementation steps are as follows:

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- (1) A vibration amplitude H is set to 4 mm, and a vibration frequency is set to 150 cycles/min, that is, an oscillation period T is 400 ms;
- (2) According to the above basic parameters, a vibration skew ratio s of the vibration curve is set to 20%, corresponding to $T_1=276$ ms and $T_2=124$ ms, thereby obtaining an angular frequency $\omega_1=\frac{\pi}{138}$ and an angular frequency $\omega_2=\frac{\pi}{62}$;
- (3) According to the above parameters, one-period position curve, vibration velocity curve, and vibration acceleration curve of vibration are obtained through formula derivation, and corresponding curves are shown in FIGS. 1, 2, and 3;
- (4) Through a cyclic oscillation process, vibration position, velocity, and acceleration curves of multiple oscillation periods are obtained, as shown in FIG. 4.
- (5) Returning to step (2), while maintaining the oscillation period constant, the vibration skew ratio is changed and sequentially set s to 0, 10%, and 20%, corresponding T_1 values are respectively 400 ms, 320 ms, and 276 ms, and corresponding T_2 values are respectively 0 ms, 80 ms, and 124 ms. Therefore, corresponding angular frequencies ω_1 are respectively $\frac{\pi}{200}$, $\frac{\pi}{160}$, and $\frac{\pi}{138}$, and corresponding angular frequencies ω_2 are respectively 0, $\frac{\pi}{40}$, and $\frac{\pi}{62}$. The subsequent steps (3) to (4) are then performed to obtain corresponding vibration position, velocity, and acceleration curves, as shown in FIGS. 5, 6, and 7.

It can be seen from the above embodiments that the non-sinusoidal vibration position curve is smooth and stable, and parameter settings may be changed according to any process value. It can be seen from the vibration velocity curve that, during an upward vibration process, velocity variation is small, and vibration rises at a stable and smooth velocity during most of the time, while the velocity is slightly reduced during one portion of the process, thereby reducing a velocity peak value, significantly reducing friction between the mold and a cast slab, and improving vibration stability. During a downward vibration process, a mold velocity changes rapidly and smoothly in a pseudo-sinusoidal manner, thereby significantly reducing negative strip time. In addition, it can be seen from the vibration acceleration curve that acceleration variation is continuous, smooth, and non-abrupt, thereby greatly reducing impact and damage to equipment, being highly equipment-friendly, and effectively prolonging a service life of the equipment.

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In summary, the method for controlling a non-sinusoidal hydraulic vibration curve of a mold realizes a stable and smooth hydraulic cylinder velocity curve and continuous and non-abrupt acceleration variation. Control parameters thereof may be changed according to any process value, and the vibration skew ratio may be arbitrarily selected within 20%, thereby achieving simple implementation, a wide application range, and strong practicability.

It is to be finally noted that the above embodiments are provided only for illustrating the technical solutions of the present invention, and not intended to limit the scope thereof. Although the present invention has been described in detail with reference to preferred embodiments, those skilled in the art will understand that various modifications and equivalent substitutions may be made to the technical solutions without departing from the spirit and scope of the invention. Such modifications and substitutions shall fall within the scope of protection defined by the appended claims.

Claims

1. A method for controlling a non-sinusoidal hydraulic vibration curve of a mold, comprising: generating the non-sinusoidal hydraulic vibration curve using a three-stage linear-sinusoidal composite function, wherein an oscillation period of a position curve comprises three stages:

a first stage being a pseudo-sinusoidal curve obtained by superposition of a standard sinusoidal function with an angular frequency of ω_1 and a linear function having a slope of $-\frac{T_1}{2\pi}a(a-1)$;

a second stage being a pseudo-sinusoidal curve obtained by superposition of a standard sinusoidal function with an angular frequency of ω_2 and a linear function having a slope of $\frac{T_1^2}{2\pi} \frac{1-a}{T_2}$ and an offset value of $\frac{T_1^2}{4\pi} \frac{a^2-1}{a}$;

and a third stage being a pseudo-sinusoidal curve obtained by superposition of a standard sinusoidal function with an angular frequency of ω_1 and a linear function having a slope of $-\frac{T_1}{2\pi}a(a-1)$ and an offset value of $-\frac{T_1^2}{2\pi}a(a^2-1)$, wherein the third stage is connected to the pseudo-sinusoidal curve of the first stage at different sampling times.

2. The method according to claim 1, wherein, according to a continuous cycle period, the three-stage linear-sinusoidal composite function is a function formed by connecting pseudo-sinusoidal curves obtained through superposition and deformation of standard sinusoidal functions having angular frequencies respectively of ω_1 and ω_2 and linear functions having different slopes.

3. The method according to claim 2, wherein the position curve equation of the non-sinusoidal hydraulic vibration curve is:

$$f(t) = \begin{cases} -\frac{T_1}{2\pi} \left(\frac{T_1}{2\pi} \sin\left(\frac{2\pi}{T_1}t\right) + a(a-1)t \right), t \in (0, \frac{T_1}{2}) \\ \frac{T_1^2}{2\pi} \left(\frac{a}{2\pi} \sin\left(\frac{2\pi}{T_2}\left(t - \frac{T_1}{2}\right)\right) - \frac{a-1}{T_2}t + \frac{a^2-1}{2a} \right), t \in (\frac{T_1}{2}, \frac{T_1}{2} + T_2) \\ -\frac{T_1}{2\pi} \left(\frac{T_1}{2\pi} \sin\left(\frac{2\pi}{T_1}(t - T_2)\right) + a(a-1)(t + T_1(a+1)) \right), t \in (\frac{T_1}{2} + T_2, T_1 + T_2) \end{cases}$$

wherein ω_1 and ω_2 are angular frequencies of two standard sinusoidal functions respectively, corresponding oscillation periods are respectively T_1 and T_2 , in units of ms; t is a sampling time of the vibration curve, in units of ms; a is a steady rising time in the vibration curve, in units of ms; and $T_2 = aT_1$.

4. The method according to claim 3, wherein a vibration velocity curve equation for one period

corresponding to the non-sinusoidal hydraulic vibration curve equation is as follows:

$$v(t) = \begin{cases} -\frac{T_1}{2\pi} \left(\cos\left(\frac{2\pi}{T_1} t\right) + a(a-1) \right), t \in (0, \frac{T_1}{2}) \\ \frac{aT_1^2}{2\pi T_2} \left(\cos\left(\frac{2\pi}{T_2} (t - \frac{T_1}{2})\right) - \frac{a-1}{a} \right), t \in (\frac{T_1}{2}, \frac{T_1}{2} + T_2) \\ -\frac{T_1}{2\pi} \left(\cos\left(\frac{2\pi}{T_1} (t - T_2)\right) + a(a-1) \right), t \in (\frac{T_1}{2} + T_2, T_1 + T_2) \end{cases}$$

5.The method according to claim 4, wherein, according to the vibration velocity curve equation and an extremum principle, times corresponding to a minimum vibration position and a maximum vibration position occurring within one period are obtained, namely times at which the vibration velocity is equal to 0;

wherein the times are obtained by the following formulas:

$$\begin{cases} -\frac{T_1}{2\pi} \left(\cos\left(\frac{2\pi}{T_1} t_{\min}\right) + a(a-1) \right) = 0, t_{\min} \in (0, \frac{T_1}{2}) \\ -\frac{T_1}{2\pi} \left(\cos\left(\frac{2\pi}{T_1} (t_{\max} - T_2)\right) + a(a-1) \right) = 0, t_{\max} \in (\frac{T_1}{2} + T_2, T_1 + T_2) \end{cases}$$

wherein:

$$t_{\min} = \frac{-T_1 \arccos(a^2 - a)}{2\pi}, t_{\max} = \frac{T_1(\pi + \arccos(a^2 - a))}{2\pi} + T_2;$$

wherein $t_{\min}$ is a time corresponding to the minimum vibration position within one period, in units of ms; and $t_{\max}$ is a time corresponding to the maximum vibration position within one period, in units of ms.

6.The method according to claim 5, wherein a vibration skew ratio is defined as a ratio of a difference between a time during which a slope of the vibration curve is positive and a time during which the slope of the vibration curve is negative within one oscillation period to the entire oscillation period, and therefore the vibration skew ratio of the non-sinusoidal hydraulic vibration curve is calculated as follows:

$$s = \frac{2(t_{\max} - t_{\min}) - T}{T} * 100\% = \frac{\pi a + 2 \arccos(a^2 - a)}{(1 + a)\pi} * 100\%$$

wherein $T = T_1 + T_2$ is a oscillation period, in units of ms, and $a = \frac{T_2}{T_1}$;

wherein, according to the above equation, the vibration skew ratio determining a waveform of the non-sinusoidal hydraulic vibration curve is related to oscillation period parameters T_1 and T_2 .

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7. The method according to claim 6, wherein a vibration acceleration curve equation for one period corresponding to the non-sinusoidal hydraulic vibration curve equation is as follows:

$$\delta(t) = \begin{cases} \sin\left(\frac{2\pi}{T_1}t\right), t \in (0, \frac{T_1}{2}) \\ -\frac{1}{a}\sin\left(\frac{2\pi}{T_2}(t - \frac{T_1}{2})\right), t \in (\frac{T_1}{2}, \frac{T_1}{2} + T_2) \\ \sin\left(\frac{2\pi}{T_1}(t - T_2)\right), t \in (\frac{T_1}{2} + T_2, T_1 + T_2) \end{cases}$$

wherein, according to the above equation, the vibration acceleration curve is composed of three standard sinusoidal function segments connected at boundaries of respective intervals, and an acceleration variation of the vibration curve varies smoothly, such that the vibration acceleration curve is a continuous smooth curve without discontinuity.