A NEW DYNAMIC CONTROL 4-MOMENT VIBRATION GENERATOR

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SUMMARY

A new rotating vibration generator, DYNAMIC CONTROL 4-MOMENT VIBRATION GENERATOR, is described which has been designed for usage in studies of large earth-mounted structures and ground. It can generate exactly sinusoidal vibration force which is instantaneously controled its magnitude, direction and frequency during operation. The 4-moment has no gear train synchronizing each other, and is directly driven by individual synchronous motor connected to a common power source of which frequency is adjustable.

The vibration generator's principle, features, performance and output are presented.

Also briefly described are its expected applications.

PRINCIPLE

Prospective Projection, and Principle of 4-MOMENT VIBRATION GENERATOR are shown in Fig. 1, and Fig. 2, respecrively.

Rotation of the four shafts with equal unbalanced moment, as shown in Fig. 2 (b), under "a certain conditions", can generate the sinusoidal resultant inertia force along the exciting direction axis X-X.

"a certain conditions" are as below;

(1) Arrangement; symmetric with respect to the axis X-X. (or Y-Y, when the exciting direction axis is Y-Y.)
(2) Magnitude of moment; exactly equal to each other.
(3) Velocity of rotation; exactly synchronized.
(4) Direction of rotation; exactly symmetric with respect to the axis X-X, (or Y-Y)
(5) Relative phase angle of gravity-center of moments; exactly symmetric with respect to the axis X-X (or Y-Y)

In 4-MOMENT VIBRATION GENERATOR, 4 shafts are driven by each synchronous motor connected to one power source, in order to satisfy the condition (3). At a constant frequency of the power source, the rpm of the synchromous motors is exactly constant and "synchronous speed", and the speed is independent of the load.

And the rotating magnetic fields of the synchronous motors are controlled so as to satisfy the condition (4), and (5). The control block diagram of NEW DYNAMIC CONTROL 4-MOMENT VIBRATION GENERATOR is shown in Fig. 3. In this system, thyristors are used as frequency inverter.

When the condition (1)-(4) are satisfied, the resultant inertia force vector $\bar{F}x$, $\bar{F}y$ are

$$\bar{F}_x = WR \cdot \omega^2 \{ e^{i(\omega t+\theta)} + e^{i(-\omega t+\theta)} + e^{i(\omega t-\theta)} + e^{i(-\omega t-\theta)} \}/g \qquad \text{Eq-1}$$

$$\bar{F}y = WR \cdot \omega^2 \{ e^{i(\omega t+\frac{\pi}{2}-\theta)} + e^{i(-\omega t+\frac{\pi}{2}+\theta)} + e^{i(\omega t+\frac{\pi}{2}+\theta)} + e^{i(-\omega t+\frac{\pi}{2}-\theta)} \}/g \qquad \text{Eq-2}$$

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Then, the resultant inertia forces may be obtained by finding the each instant component of the vectors along the exciting directions, respectively,

$$Fx=Fy=4WR\cdot\omega^2 Cos\theta\cdot Cos\omega t \qquad \text{Eq-3}$$

Where, $\bar{Fx},\bar{Fy}$:Resultant inertia force vectors with respect to the axis X-X. Fx,Fy:Resultant inertia forces along the axis X-X, and Y-Y, respectively. WR:Unbalanced moment per Shaft. ω:Angular Velocity of Shaft. t:Time. θ:Phase angle of gravity center of unbalanced moment. e:Base of natural Logarithms. i:Imaginary unit. g:Acceleration of gravity.

Equation (Eq-3) shows that Fx and Fy are;

(1) Varied sinusoidally

(2) Proportional to $Cos\theta$
When the phase angles θ are changed from 0 to $\pi/2$, or from $\pi/2$ to 0 by shifting the revolving magnetic field of the motors electrically, the magnitude of the force Fx, or Fy varies instantaneously from its maximum to 0, or from 0 to its maximum.

(3) Proportional to WR, unbalanced moment per shaft.
In this vibration generator, the unbalanced moment on one shaft consists of two half-unbalanced-moments in order to extend the range of the value of WR, as shown in Fig. 1, and they are equipped on the shaft at some included angle which is symmetrical with respect to a fixed radius. The smaller the included angle is settled, the value of WR becomes larger as shown in the Fig. 2 (C). Settling of included angles are made manually. The ratio of WR maximum to WR minimum was about 30, in case of some prototype vibration generator.

PERFORMANCE & OUT-PUT SIGNALS

Performance; Resonant Load Performance Envelope, in case of prototype, F= 5,000kg, Total moment=9,000kg-cm, is shown in Fig. 4.

Regulation of period of frequency is less than 0.02% F.S, and instantaneous speed regulation is less than 0.4% (2Hz).

Automatic Control;

Constant moment, and Constant vibration force vector control are aveilable.

Setting variables;

Exciting frequency (0.01 Hz minimum,D), Total unbalanced moment (D), Vibration force vector (D&A) can be set, where, D,A show digital or, analog indicator respectively.

Indicating Variable;

Frequency (D), Total moment (D&A), Vibration force vector (D&A), Acceleration at the vibration generator (A) are indicated.

Out-put signal;

Instantaneous value of vibration force (A), Signal pulse indicating the time when vibration force is equal to 0, and 4 pulse-sequences of each shaft.

FEATURES

The new vibration generator has many excellent features, as below;

(1) Vibration force vector can be dynamically controlled during operation.
Automatic constant moment control, and automatic constant vibration force vector control can be delivered in any range within the performance envelope shown in Fig. 4.
(2) Exciting directions are changeable during operation.
(3) Multiple synchronized operation can be easily done. (Ref. APPLICATION)
(4) Wide design Limitation
Maximum rating vibration force vector: about 200 ton per one generator.
Range of frequency: 0.5 - 30 Hz
(5) Easy system for analyzing vibration. (Ref. PERFORMANCE & OUT-PUT SIGNAL)
(6) Low noise, Less than 85 dB 1 meter apart from the generator at condition of frequency 20 Hz.

APPLICATIONS

Some applications other than ordinary test may be expected as below.
(1) Measuring seismic wave through soil or rock. (Fig. 6,7)
(Utilization of correlation technique, and "FEATURES"-(1))
If the vibration force generated in this 4-MOMENT VIBRATION GENERATOR is controlled by the electric signal wave of "M SEQUENCE"=m(t) (maximum period null sequence which is a kind of random signal having a period, and the amplitude varying from 0 to 1), vibration waves similar to the signal wave in envelope=y(t) travels through ground. By finding cross-correlation function of $m'(t)$ and $y^2(t)$, we can estimate traveling time of the seismic wave. Where, $m'(t)$ is a shifted function of $m(t)$ varying from -1 to 1, and $y^2(t)$ is square function of $y(t)$.
(2) Instantaneous vibration test:
In order to minimize number of forced vibration waves dilivered to the testing soil, the 4-MOMENT VIBRATION GENERATOR may be used in such a operation that the magnitude of force is instantly built up from zero to its maximum, and instantly put out from its maximum to zero in few seconds. Fig. 5 shows the record of vibration forces and etc., during controlling the vibration force from zero to some value instantaneously.
(3) Multiple synchronized operation
Some application utilizing "FEATURES"-(3) are available, as below;
Multiple exciting test; for multiplying vibration force.
Tortional test or rocking test;
Locating two 4-MOMENT VIBRATION GENERATOR in parallel with each other, separately at some distance, and then excit in opposite senses with each other, horizontally or vertically, respectively.

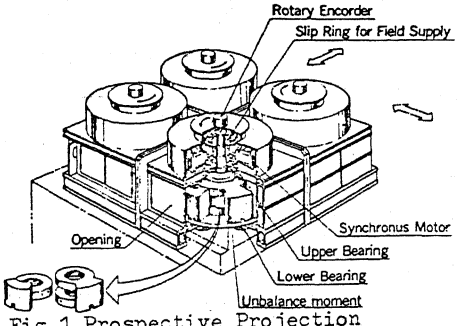

Fig.1 Prospective Projection of 4-Moment vibration Generator

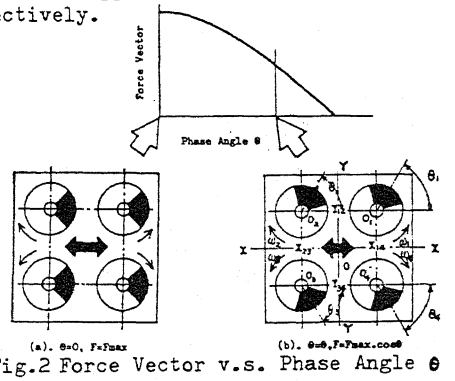

Fig.2 Force Vector v.s. Phase Angle θ

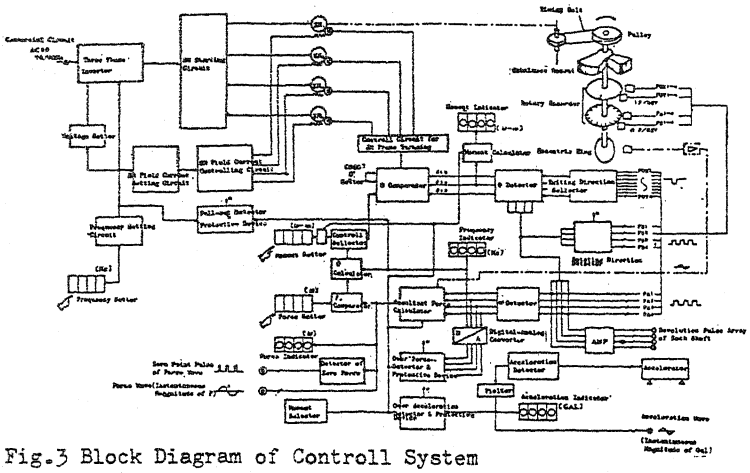

Fig.3 Block Diagram of Controll System

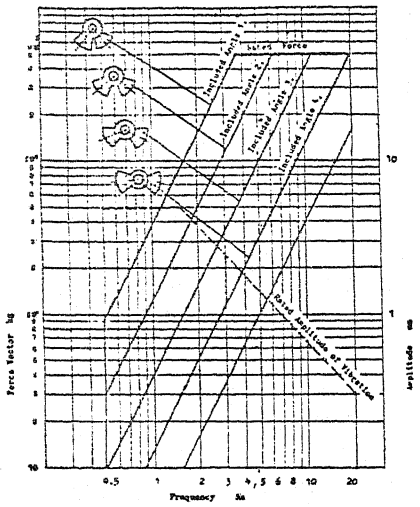

Fig.4 Resonant Load Performance Envelopes

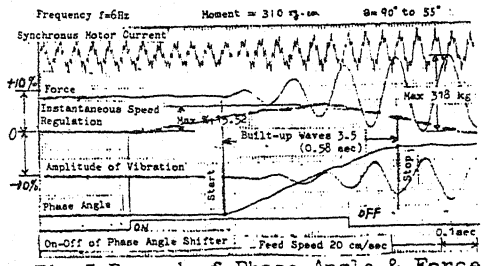

Fig.5 Record of Phase Angle & Force at Instantaneous Controlling

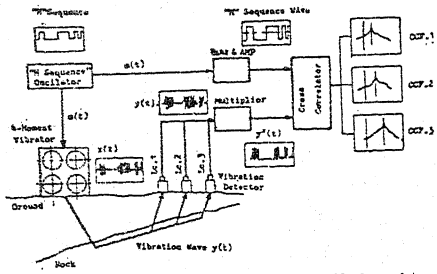

Fig.6 Sketch of Measuring Velocity of Seismic wave through Soil.

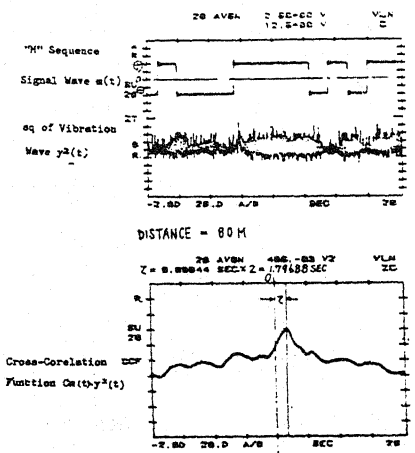

Fig.7 Waves and Cross-Corelation Function of m'(t) and ẏ²(t).