# An artificial bee colony algorithm for solving hydraulic shaking table acceleration harmonic estimation problem


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**ABSTRACT**

**Hydraulic shaking table is an important device to stimulate vibration environment, which has been widely applied to seismic simulation, aerospace and construction engineering. However, the response from the hydraulic shaking table are not considered sinusoid waveform when corresponds to a sinusoidal acceleration excitation due to the presence of harmonic distortion. This work presents an approach based on the artificial bee colony (ABC) algorithm for the harmonic component estimation in a hydraulic shaking table. The results demonstrate that the proposed method can precisely identify the harmonic component and it has great advantage of convergence as well as real-time performance.**


## INTRODUCTION

The hydraulic shaking table has been widely used in seismic simulation, aerospace and construction engineering due to its superior characteristics of higher force-to-weight ratio, higher response speed and excellent control performance [1, 2]. However, there are many nonlinear factors, such as servo valve characteristic, friction in system and specimen noise in transducer, which cause amplitude attenuation, phase shift and harmonic distortion [3]. This adversely affects the control precision, stability and signal reproduction of the hydraulic shaking table.

To suppress the harmonic distortion, various methods have been proposed to estimate the harmonic information [4]. The most commonly used algorithm is fast Fourier transform (FFT), which is good for noise suppression but has some drawbacks of spectral leakage, aliasing and


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picket fence effect [5]. In addition, Kalman filter was proposed to overcome above shortcomings and eliminate the pitfalls present in FFT algorithm [6]. Alhaj et al. studied Least Mean Square (LMS) algorithm to estimate amplitude, phase and frequency of a distorted power signal [7]. Ren and Kezunovic presented the wavelet packet transform to estimate frequency and harmonic parameters in power system [8]. The development of artificial intelligence algorithm has encouraged the researchers to use these methods for harmonic estimation. Krismanto developed radial basis function (RBF) neural network to dynamically estimate each harmonic component for converter waveform [9, 10]. Bettayeb and Qidwai proposed a technique by using genetic algorithm (GA) to detect harmonic amplitude from deteriorated power quality signal [11]. Yao et al. used particle swarm optimization (PSO) to identify the amplitude and phase of harmonic as well as fundamental acceleration output [12]. Ray and Subudhi presented bacterial foraging optimization (BFO) hybridized LMS method for the estimation of amplitude and phase in distorted power system signal [13].

From the above discussion, it can be seen that harmonic estimation mainly concentrated on the power system. Compared with power system, hydraulic servo system requires a high level of rapidity and accuracy. Fast and precise harmonic detection algorithm is essential for the effective harmonic estimation. To achieve this goal, the ABC algorithm is applied to online identify the harmonic in the sinusoidal vibration test. The results demonstrate that the proposed method can precisely identify the harmonic component and it has great advantage of convergence as well as real-time performance.

## 2 SYSTEM DESCRIPTION

Fig 1 shows the structure of single-DOF hydraulic shaking table. The size of the shaking table is 900mm×700mm×26mm and its weight is 44.23 Kg. The maximum velocity, maximum acceleration are 1.43m/s and 14m/s$^2$, respectively. The maximum force provided by actuator can achieve 4.7KN. The supply pressure is 8MPa and the system working frequency is 0-30 Hz.

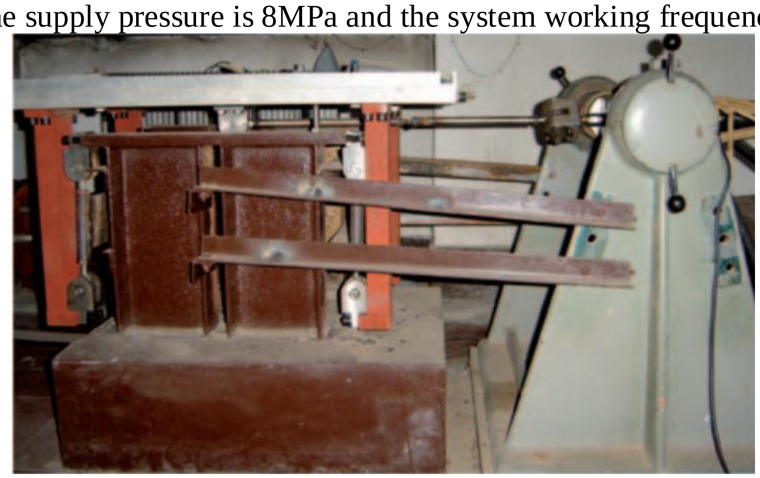

*Fig. 1. The hydraulic shaking table*

The control principle of hydraulic shaking table is shown in Fig 2. The feedback velocity is synthesized from the measured displacement and acceleration of the shaking table. The three variable controller (TVC) compares the feedback signal and the input signal to generate the control signal, which controls the servo valve to release fluid to the appropriate port of its hydraulic actuator. The actuator movement offers precise control over displacement output to simulate the desired motion.

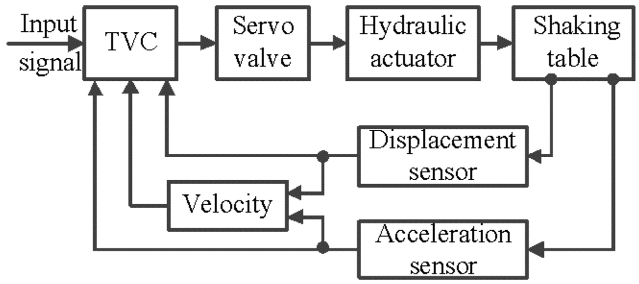

*Fig.2. Control principle of the hydraulic shaking table*

## 3 ARTIFICIAL BEE COLONY ALGORITHM

The ABC algorithm is a swarm intelligent optimization algorithm, which was proposed by Karaboga in 2005 for solving high dimensional optimization problems [14, 15]. It was inspired by the intelligent foraging behavior of honey bees. Although self-limited of individual bee, the whole colony is able to discover quality nectar source under unifying leadership. The ABC algorithm concludes three common components: food sources, employed bees and unemployed bees, and unemployed bees consist of onlooker bees and scout bees. Every employed bee of the colony corresponds to a specific food source. That is, the number of employed bees is equal to the number of food sources. Firstly, a series of positions of food sources is randomly assigned to employed bees. Afterwards, these bees share the quality of food sources with other bees waiting for dance area. Every onlooker bee employed herself at the most profitable source by waggle dance. The more profitable nectar source, the more probability of onlooker bees choose the profitable food source. If the nectar source is better than it was, onlooker bees turn to remember the latest nectar source and abandon the old one. The employed bees of an abandoned food source become scout bees.

ABC algorithm consists a population of food sources. Similar to other evolutionary algorithms, it generates an initial population of food sources randomly. For parameter *j* in food source *i*, the initial value $\phi_{ij}$ is calculated by

$$\phi_{ij} = l_j + rand(0,1) \times (u_j - l_j) \tag{1}$$

where *i*=1,2, …, NP and *j*=1,2, … , D. NP is the size of population and D represents the number of optimization variable. $u_j$ and $l_j$ represent the predefined upper and lower bound of variable, respectively.

After initialization, the solutions are subjected to a set number of iteration in the search process of employed bees, onlooker bees and scout bees. An employed bee and onlooker bee probabilistically produces a modification of the solution in her memory for finding a new food source and evaluates the nectar amount of the new source. The search process is defined as follows

$$v_{ij} = \varphi_{ij} + \alpha_{ij}(\varphi_{ij} - \varphi_{kj}) \tag{2}$$

where *k*= 1,2,…,BN. BN is the number of employed bees, k and j are the different values randomly distributed. $\alpha_{ij}$ is a random number between [-1,1].

Onlooker bees evaluate the fitness value of nectar source and choose a nectar source by roulette wheel selection. The probability of selecting a food source *i* by an onlooker bee is denoted by $p_i$, which is calculated by

$$p_i = \frac{fit_i}{\sum_{i=1}^{NP} fit_i} \tag{3}$$

where $fit_i$ is the fitness value of food source $i$ evaluated by the employed bee, which is proportional to the nectar amount of the food source. In this way, employed bees have completed the exchange of information with onlooker bees.

The $fit_i$ is calculated by

$$fit_i = \begin{cases} \dfrac{1}{1+f_i} & \text{if } f_i \geq 0 \\ 1+abs(f_i) & \text{otherwise} \end{cases} \tag{4}$$

Fig 3 presents the process of ABC algorithm.

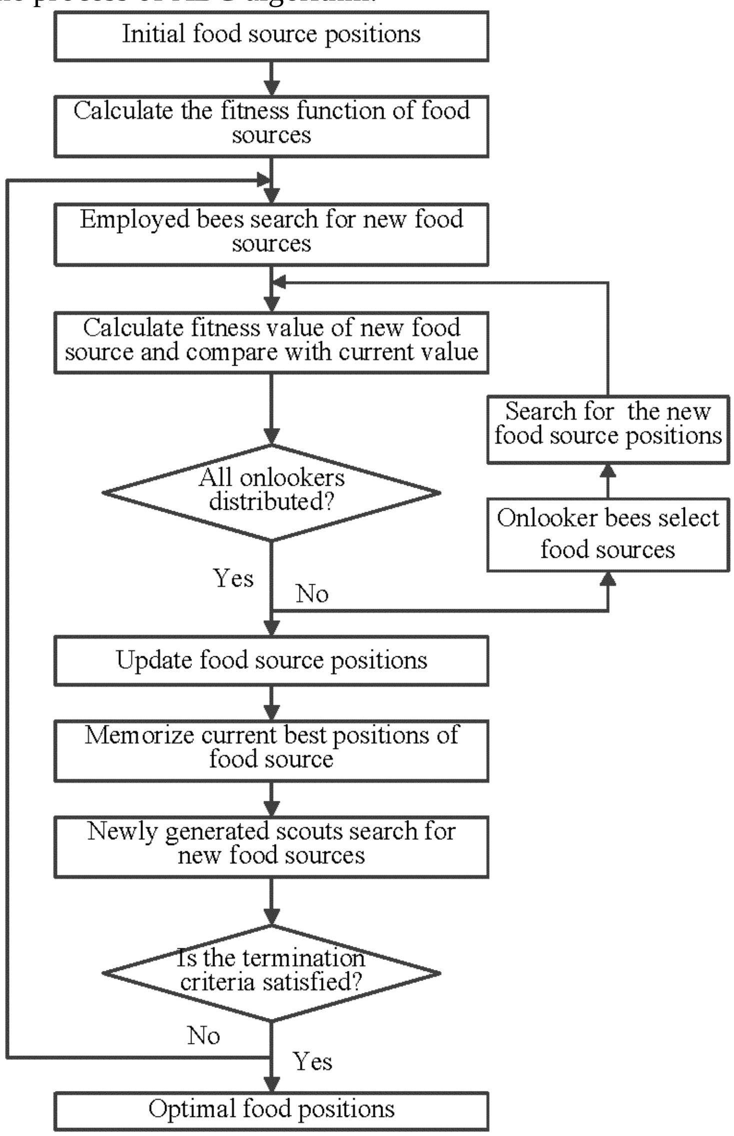


*Fig.3. Flow chart of the ABC algorithm*

## 4 HARMONIC ESTIMATION PROBLEM

The harmonic's frequencies are integer multiples of the fundamental frequency, so the distorted sinusoidal acceleration response can be expressed as

$$a(t) = \sum_{n=1}^{N} A_n \sin(\omega_n t + \phi_n) \tag{5}$$

where $n=1,2,\cdots,N$ represents the order of the harmonic; $A_n$ , $\phi_n$ and $\omega_n$ are the amplitude, phase and angular frequency of the $n$th harmonic, respectively.

The discrete time version of Eq. (5) can be represented as

$$a(k)=\sum_{n=1}^{N} A_n \sin(\omega_n kT_s+\phi_n) \tag{6}$$

where $T_s$ is sampling period. For estimation amplitude and phase, Eq. (6) can be rewritten as

$$a(k)=\sum_{n=1}^{N} A_n \sin(\omega_n kT_s)\cos\phi_n + A_n \cos(\omega_n kT_s)\sin\phi_n \tag{7}$$

The sinusoidal acceleration response in parametric form becomes

$$a(k)=X^{\mathrm{T}}(k)\times W(k) \tag{8}$$

where $X(k)$ and $W(k)$ denote input vector and weight vector, respectively.

$$X(k)=\left[\sin(\omega_1 kT_s), \cos(\omega_1 kT_s), \cdots, \sin(\omega_N kT_s), \cos(\omega_N kT_s)\right]^{\mathrm{T}}$$

$$W(k)=\left[A_1\cos(\phi_1), A_1\sin(\phi_1), \cdots, A_N\cos(\phi_1), A_N\sin(\phi_1)\right]^{\mathrm{T}}$$

The weight vector can be updated as

$$W(k)=\left[W_{11}(k), W_{12}(k), \cdots, W_{N1}(k), W_{N2}(k)\right]^{\mathrm{T}}$$

The estimation model of this algorithm is

$$\hat{a}(k)=X^{\mathrm{T}}(k)\times\hat{W}(k) \tag{9}$$

The estimate $\hat{W}(k)$ for the requested $W(k)$ can be obtained by minimizing the objective function

$$J=\sum\left[a(k)-\hat{a}(k)\right]^2 \tag{10}$$

After updating of the weight vector, amplitude and phase of fundamental as well as nth harmonic parameters are derived as

$$A_n=\sqrt{W_{n1}(k)+W_{n2}(k)} \tag{11}$$

$$\phi_n=\tan^{-1}\left(W_{n2}/W_{n1}\right) \tag{12}$$

The harmonic estimation process based on ABC algorithm can be illustrated with Fig 4.

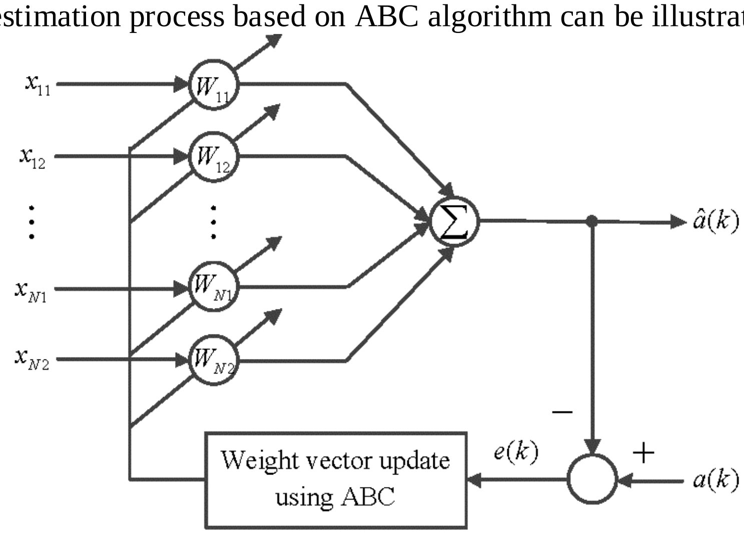


*Fig.4. Block diagram of the ABC algorithm.*

## 5 SIMULATION RESULTS AND DISCUSSION

In order to validate the proposed harmonic estimation algorithm, the simulation signal containing eighth harmonics is carried out.

$$a(t) = 14\sin(10\pi t) + 12\sin(20\pi t + 0.1) + 10\sin(30\pi t - 1.2) + 8\sin(40\pi t + 0.8) + 6\sin(50\pi t - 0.2)$$
$$+ 4\sin(60\pi t - 0.6) + 2\sin(70\pi t + 1.2) + \sin(80\pi t - 0.8)$$

Fig 5 and Fig 6 represent the estimated amplitude and phase of fundamental response as well as each harmonic. Large fluctuation at the beginning of the estimation, but they tend to be stable after 2 s. The estimated values of amplitudes and phases when they are stable state are very close to its original values, which means the proposed estimation scheme can identify harmonic information efficiently.

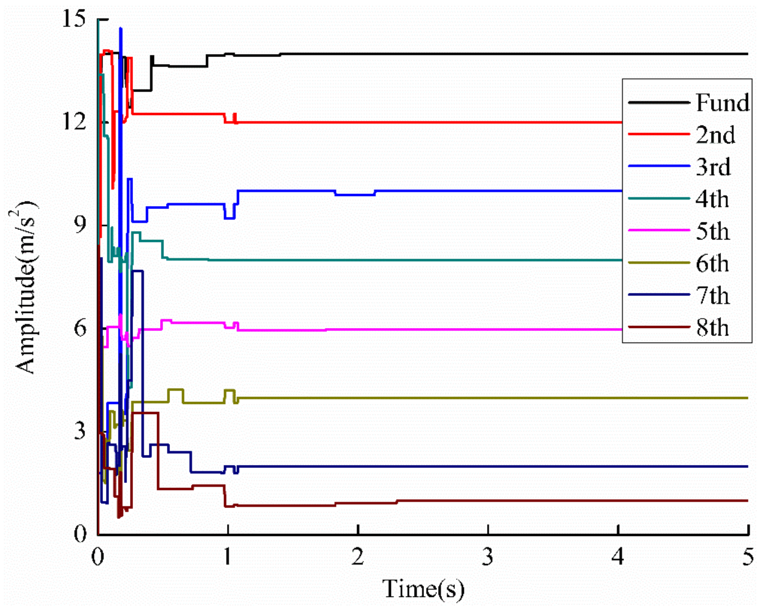


*Fig.5. The estimated amplitude*

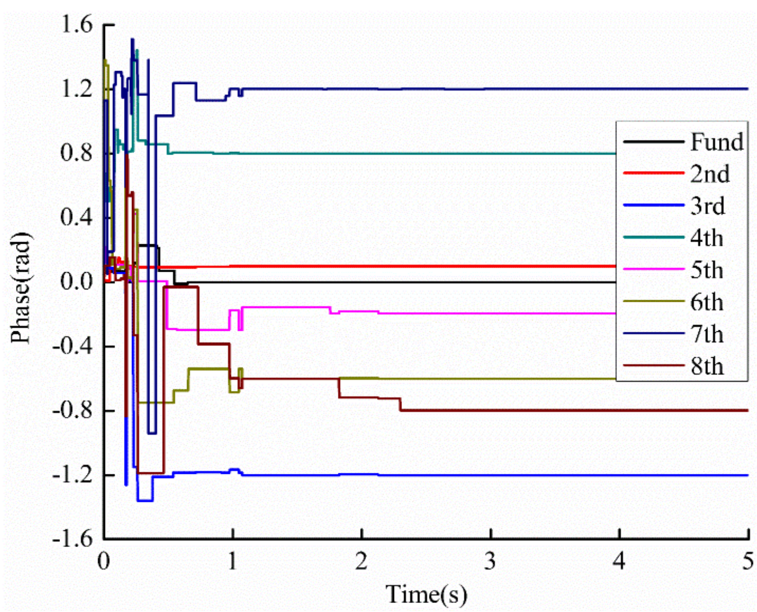


*Fig.6. The estimated phase*

The original signal and the estimated signal based on ABC algorithm are show in Fig 7, from which it can be seen that there is small error between the original signal and the estimated signal after 0.4s. This means that the harmonic information is detected precisely.

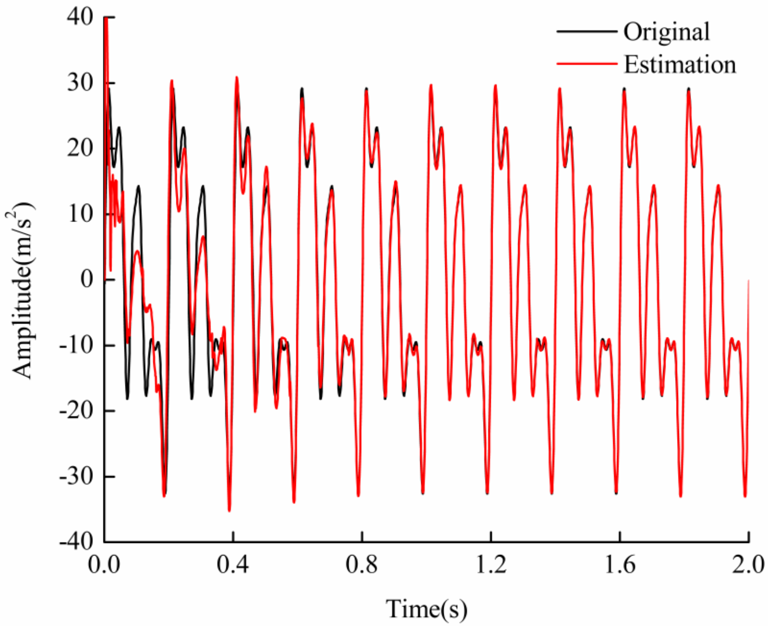


*Fig.7. The estimated signal*

## 6 CONCLUSIONS

The sinusoidal shaking test is often used to stimulate periodic vibration environment. Unfortunately, harmonic distortion influence the control performance of hydraulic shaking table. In order to suppress harmonic distortion, it is first necessary to obtain the amplitude and phase of fundamental and various orders of harmonics. Simulation results show that the ABC algorithm can accurately estimate the amplitude and phase of each harmonic, which gives us enough confidence to apply it in real shaking table experimental.

## 7 ACKNOWLEDGMENTS


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