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UNIAXIAL SHAKING MACHINE OF GROUND MOTION SIMULATION

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Abstract— In the race of growing vertically, we are moving towards tall buildings. Such a tall structure needs a deep understanding of the structural behaviour under dynamic forces. A uniaxial shaking machine simulates the earth surface during earthquake creating identical vibrations by using time history function as the input. This machine comprises of a flat surface which will be used as a fix base of structural model made up of light structural members. This machine will give us the acceleration v/s time graph and relative drift as output which can further be used to understand the behaviour of different structural models with different damping system or bracing arrangements by comparing their output curves with the common input time history function.

Index Terms— Accelerometer, Arduino, Earthquake, shaking machine, stepper motor, Sympsons 1/3rd rule, Time-history function.

1 INTRODUCTION

Frequency is the inherent property of a any system i.e. every building or structure has its own frequency commonly named as natural frequency which depend on its mass and stiffness, when a ground moves in the frequency which is similar to the natural frequency of above structure it will undergo maximum oscillation. Generally, a tall building will respond to low-frequency oscillation and short building respond to high frequency oscillation, a medium-height building responds to medium-frequency oscillation and it may happen than in this range of frequency tall and short building might not be affected. That's why it is important to study the ground motion or in other words we say seismic waves produce during earthquake.

For better understanding of the behaviour of our structure we need a device which simulate the actual motion of the earth during earthquake by which we can check stability of building models, stability of components of building like beam column. Assessment of dynamic and seismic behaviour of structures.

2 MAIN COPONENTS

2.1 Stepper Motor

Stepper motor is a DC motor that move in discrete steps, it is a synchronous brushless motor where a full rotation is divided into a number of steps usually 200 steps in a full rotation i.e. 1.8o per step. There are multiple coils, that are organised in group called "phases". By energizing each phase in sequence, the motor will rotate one step at a time. A stepper motor is used in devices that need precise positioning and speed control. Because it moves in precise repeatable steps, the stepper motor is used in devices like 3D printers, camera platforms, plotters, scanners, etc. stepper motor will give maximum speed at minimum torque and as torque increase the speed of stepper motor decreases.

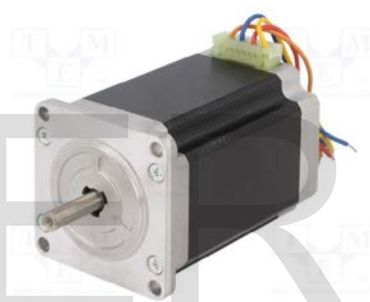

Fig1: Nima 23 Stepper Motor

2.2 Ball Screw and Bearing

Ball screw is a device which convert the rotational motion into linear motion, it consist of two parts screw and a nut, each with matching helical grooves, and balls which roll between these grooves providing the only contact between the nut and the screw. The screw is connected to rotating object and nut is connected to object which is to be move linearly, the gap between the helical grooves of screw and nut is filled with metal balls so the friction between them is minimised and higher efficiency (above 90%) is achieved.

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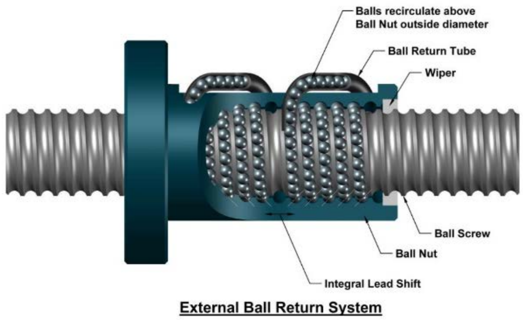

Fig2: External Ball Return System (Ball screw)

2.3 Arduino, Driver, Adaptor

Arduino-Uno is an open source microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It simply connects to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

Sensor The MPU-6050 devices combine a 3-axis gyroscope and a 3-axis accelerometer on the same silicon die, together with an onboard Digital Motion Processor (DMP), which processes complex 6-axis MotionFusion algorithms.

Driver The TB6600 single axis driver is a micro-stepping driver. It is used for driving 4-phase hybrid stepper motors.

Fig3: Driver TB6600

2.3 Top Flat Surface

A flat horizontal surface will act as a piece of land on which the building model is placed and it is provided with number of holes for proper fixing of the building model and this flat surface will also give support to the sensors and pay load.

2.4 Bolts, Nuts, and Clips

Various different types of bolts, nuts and clips are use to hold the bearing, motor and ball screw in their position such that the vibration cause by motor does not affect them.

3 Specifications of Components Used

- Nema 23 stepper motor 10 kg/cm torque, 1.8^{o} (Deg.) per step.
- AXIL Ro smps adaptor power supply (36volt, 2 amp).
- Stepper driver TB6600 3.5amp (peak 4amp), input supply 9-40 VDC.
- MPU 6050- (gyrometer + accelerometer) MEMS Motion Tracking.
- Arduino UNO.
- Voltage Regulator (Buck Convertor) DC-DC stepdown.
- Ball screw- 1rotation = 10 mm.

4 Mechanism

Depends on the required output (sinusoidal or random), input is selected for a given model, for example we need a random shaking as it happens in a reality, we are using time history function as a input, time history function is the recorded data of the previously happened earthquake in the form of series of values of the acceleration after small time interval (0.02 sec or 0.01 sec). The below graph is the time history curve of a small earthquake of about 5 second, X-axis represents the time and Y-axis represents the magnitude of the acceleration in centimetre per second square.

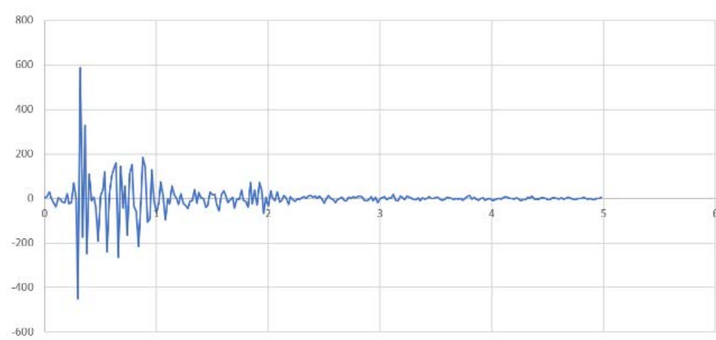

Fig4: Time history function

Now we have to convert these digital numerical values into mechanical output and for that we convert these series of values of acceleration into velocity and then into displacement by integrating all values using Simpsons $^{1/3}$ rule. As stepper motor works on steps (200 step in 360^{o} rotation) and velocity which means how much step it should run and by which velocity, so we need to change our input data(displacement) into steps. We know the specification of our ball screw is that its nut move 1

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centimetre when we rotate the screw by 360°, now by using this relationship that 360° rotation or 200 steps will give us 1 cm or 10 mm displacement, we can find how much step our stepper motor needs to run in 0.02 time interval. As we have a series of values of displacement in 0.02 second of time interval, we are putting these values into Arduino code which will run our stepper motor.

$$\int_{a}^{(a+2h)} f(x)\,dx = \frac{h}{3}\left[f(a) + 4f(a+h) + f(a+2h)\right]$$

Simpsons 1/3rd Rule

	A	B	C	D	E	F	G
1	time	acc(cm/sec2)	velocity(cm/sec)	displacement(cm)	relative displacement(cm)	no of step	speed
2							
3	0	3.522	-0.755546667	0.018104356	0.018104356	3.6208712	54.313068
4	0.02	7.015	0.83636	0.003892356	-0.014212	-2.8424	-42.636
5	0.04	29.015	0.12576	-0.026676889	-0.030569244	-6.113848889	-91.70773333
6	0.06	2.379	-0.755546667	-0.035899956	-0.009223067	-1.844613333	-27.6692
7	0.08	-19.667	-1.105106667	-0.014038489	0.021861467	4.372293333	65.5844
8	0.1	-37.043	-0.20902	-0.009646489	0.004392	0.8784	13.176
9	0.12	2.073	-0.164586667	-0.019744667	-0.010098178	-2.019635556	-30.29453333
10	0.14	-2.602	-0.579606667	-0.014940489	0.004804178	0.960835556	14.41253333
11	0.16	-16.353	-0.478686667	-0.0006064	0.014334089	2.866817778	43.00226667
12	0.18	-18.927	0.25328	-0.016111022	-0.015504622	-3.100924444	-46.51386667
13	0.2	20.258	-0.625393333	0.002881644	0.018992667	3.798533333	56.978
14	0.22	-24.113	-0.16836	0.028039378	0.025157733	5.031546667	75.4732
15	0.24	-17.615	1.73108	-0.110684311	-0.138723689	-27.74473778	-416.1710667
16	0.26	69.319	-2.550053333	-0.157226578	-0.046542267	-9.308453333	-139.6268
17	0.28	0.001	-8.133513333	0.262555467	0.419782044	83.95640889	1259.346133
18	0.3	-451.831	11.50012	0.156993422	-0.105562044	-21.11240889	-316.6861333
19	0.32	587.296	1.516353333	0.145025022	-0.0119684	-2.39368	-35.9052
20	0.34	-172.335	5.98348	-0.050868711	-0.195893733	-39.17874667	-587.6812
21	0.36	329.497	-3.69652	0.009871867	0.060740578	12.14811556	182.2217333
22	0.38	-248.131	1.172293333	0.019576578	0.009704711	1.940942222	29.11413333
23	0.4	108.549	0.488126667	-0.017264933	-0.036841511	-7.368302222	-110.5245333
24	0.42	-10.221	-0.188313333	-0.098867289	-0.081602356	-16.32047111	-244.8070667
25	0.44	5.554	-2.324613333	-0.162652044	-0.063784756	-12.75695111	-191.3542667
26	0.46	-40.242	-5.343326667	-0.041165911	0.121486133	24.29722667	364.4584
27	0.48	-193.278	-0.699886667	0.060226044	0.101391956	20.27839111	304.1758667
28	0.5	11.855	1.967986667	0.026185689	-0.034040356	-6.808071111	-102.1210667
29	0.52	40.875	1.861846667	-0.136224889	-0.162410578	-32.48211556	-487.2317333
30	0.54	119.843	-5.48752	-0.020298622	0.115926267	23.18525333	347.7788
31	0.56	-240.97	-0.3455	0.134805511	0.155104133	31.02082667	465.3124
32	0.58	20.909	3.824726667	0.188720267	0.053914756	10.78295111	161.7442667

Fig5: Screenshot of Excel File

For taking output values of acceleration by which our top surface is moving, we are using accelerometer sensor which will be placed on top surface connected to the Arduino and give us the values after every 0.02 second of time interval and we will again make the graph of these values and can compare the input and output curve.

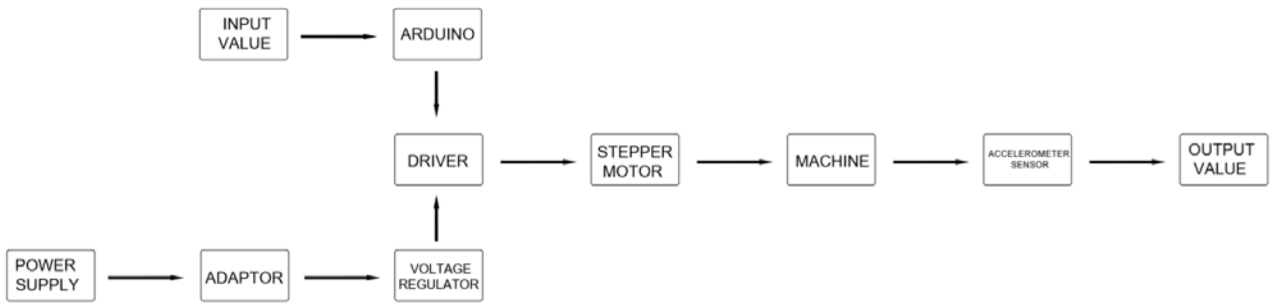

Fig6: Testing Model

5 CONCLUTION

Shaking machine is the device which can be use for comparing the different structural model. Here we had used the stepper motor and ball screw for simulate the motion of the earth during the earthquake, if we compare both the time history curve and output curve which we generated through our mechanism, the shaking machine is doing good for low values of acceleration but can't produce very high acceleration as the maximum velocity of our stepper motor is limited. For producing the exact shaking or to achieve the exact time history curve we need to use high torque stepper motor with better gere assembly which will reduce the loss of micro steps while operating the machine, still for random shaking this kind of shaking machine can be use.

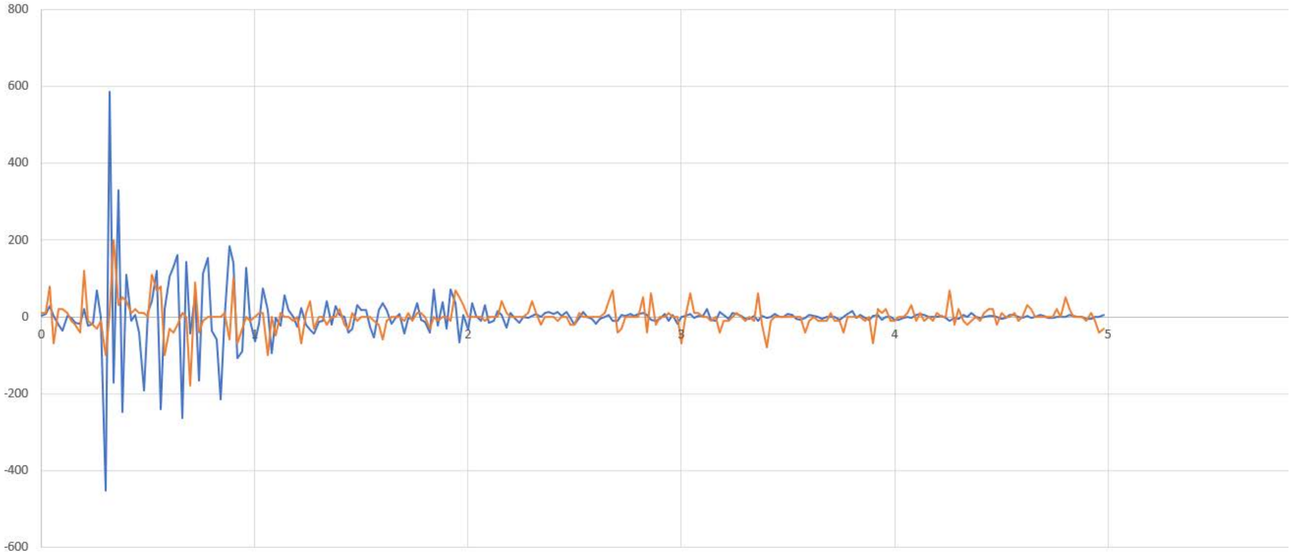

Fig7: Comparison between input time history function and output accelerometer value
Blue colour- input
Orange colour- output

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