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# Guitar Playing Robot

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**Abstract:** The paper deals with guitar playing robot, which is able to play any song. Paper explores only electromechanical parts of robot with aim to build prototype of the robot. Robot is dedicated for educational purpose. Also functional experiments have been executed with actuators for strumming and also own concept of actuator has been developed for pushing of string.

**Keywords:** *guitar robot, actuator, sensor, servo.*

## 1. Introduction

Guitar as music instrument belongs to category of string instruments. Preloaded steel wire is used for generating of tones. There are several famous activities in this are like robotic guitar, which can replace group of three guitarists. Guitar robot has guitar-strumming mechanism and playing is precise and much faster than human playing (fig. 1).

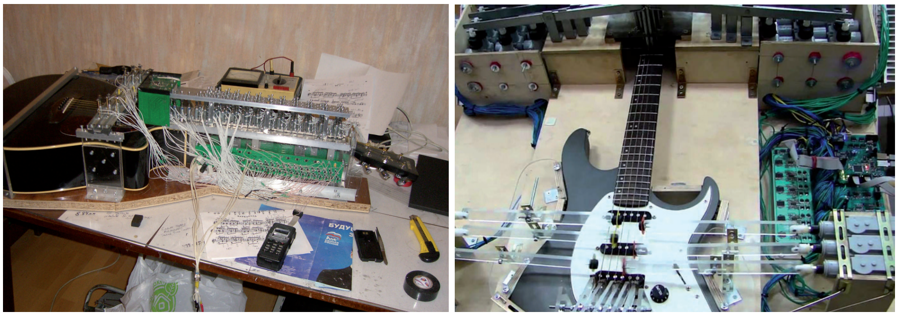

Fig. 1: *Robotic guitar.*

Z-Machines (fig. 2) is the robot band, which contains also guitarist robot with 78 fingers sweeping across the glowing instrument strapped to its torso. Z-Machines are created by engineers at the University of Tokyo, the robot band uses around 300 kilowatts of electricity. "Just like when you're writing music for a human, there are certain possibilities and certain limits. The robot guitarist for example, can play much faster than a human ever could, but there is no amplification control.".

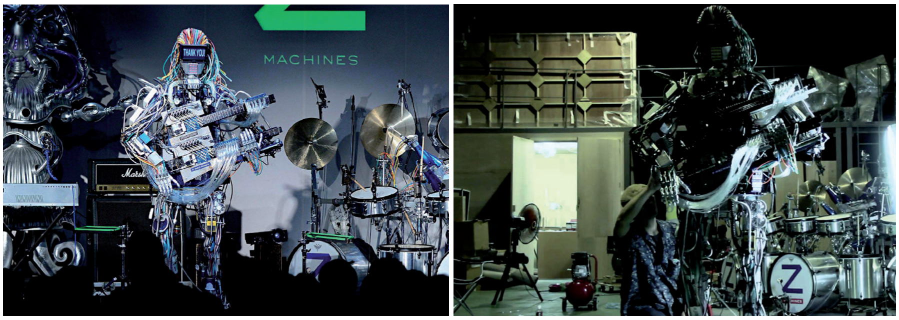


Fig. 2: *Z-Machines - guitar robot.*

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Aim of this work is to design guitar robotic system. Limiting conditions are:

- *robot will play on standard spanich guitar,*
- *guitar cannot be damaged with holes, glue or other bonding technologies.*

## 2. Basic assumptions and description of the problem

There is an equation between the stress and deformation of guitar spring wire (if we suppose the elastic deformation in range of validity of Hooke law):

$$\sigma = \frac{F}{S} = E \cdot \frac{\Delta L}{L_0} \tag{1}$$

where: $\sigma$ – stress in spring wire, $F$ – axial force of tightening, $E$ – Youngs modulus, $\Delta L$ – deformation, $L_0$ – initial length of spring wire.

Guitar wire is made from music wire (ASTM A228) with high strength and excellent fatigue life (E=207GPa).

To get the correct tone from the string, a approximately preload tension of 200N has to be applied.

Sound wave is created as a result of a vibrating object. The vibrating object is the source of the disturbance that moves through the medium. Any object that vibrates will create a sound. The sound could be musical or it could be noisy; but regardless of its quality, the sound wave is created by a vibrating object. Nearly all objects, when hit or struck or plucked or strummed or somehow disturbed, will vibrate. If you pluck a guitar string, it will begin to vibrate. The frequency or frequencies at which an object tends to vibrate with when hit, struck, plucked, strummed or somehow disturbed is known as the natural frequency of the object. If the amplitudes of the vibrations are large enough and if natural frequency is within the human frequency range, then the vibrating object will produce sound waves that are audible. The actual frequency at which an object will vibrate at is determined by a variety of factors. Each of these factors will either affect the wavelength or the speed of the object. Since frequency = speed/wavelength an alteration in either speed or wavelength will result in an alteration of the natural frequency. The role of a musician is to control these variables in order to produce a given frequency from the instrument that is being played.

Guitar generally has six strings, each having a different linear density *(the wider strings are more dense on a per meter basis),* a different tension *(which is controllable by the guitarist),* and a different length *(also controllable by the guitarist).* The speed at which waves move through the strings is dependent upon the properties of the medium - in this case the tightness *(tension)* of the string and the linear density of the strings. Changes in these properties would affect the natural frequency of the particular string. The vibrating portion of a particular string can be shortened by pressing the string against one of the frets on the neck of the guitar. This modification in the length of the string would affect the wavelength of the wave and in turn the natural frequency at which a particular string vibrates at. Controlling the speed and the wavelength in this manner allows a guitarist to control the natural frequencies of the vibrating object *(a string)* and thus produce the intended musical sounds. The same principles can be applied to any string instrument - whether it is the harp, harpsichord, violin or guitar.

Once the speed of propagation is known, the frequency of the sound produced by the string can be calculated. The speed of propagation of a wave is equal to the wavelength $\lambda$ divided by the period $\tau$, or multiplied by the frequency $f$:

$$v = \frac{\lambda}{\tau} = \lambda \cdot f \tag{2}$$

where: $\lambda$ – wavelength, $\tau$ – period, $f$ – frequency.

If the length of the string is $L$, the fundamental harmonic is the one produced by the vibration whose nodes are the two ends of the string, so $L$ is half of the wavelength of the fundamental harmonic. Hence one obtains Mersenne's laws:

$$f = \frac{v}{2 \cdot L} = \frac{1}{2 \cdot L} \cdot \sqrt{\frac{T}{\mu}} \tag{3}$$

where: $T$ – tension of string, $\mu$ – linear density of string (mass per unit length), $L$ – length of vibrating string.

Therefore: the shorter the string, the higher the frequency of the fundamental; the higher the tension, the higher the frequency of the fundamental; the lighter the string, the higher the frequency of the fundamental.

Consequently, playing on guitar consists of two activities – strumming and pushing of strings. Also concept of robot will consist of two mechanisms for ensuring of these activities. Encompassment of these problems will need very good design of mechanical parts and actuators for strumming and pushing. Also new own concept of actuator has been developed for pushing of string.

## 3. Experiment with strumming actuators

Basic principle of sound generating is resounding (vibration) of preloaded guitar wire string. This generating is possible to make through the linear or swinging motion. Wire is axially preloaded and it is complicated to count minimum force for vibration making. That is the reason of experimentally way solution of the problem (fig. 3). Three servos have been selected for strumming experiment:

- *Hitec HS 55 (maximum torque 1.3 Nm, maximum velocity 0.98 rps),*
- *Hitec HS 82 (maximum torque 3.4 Nm, maximum velocity 1.38 rps),*
- *Hitec HS 645MG (maximum torque 9.6 Nm, maximum velocity 0.69 rps).*

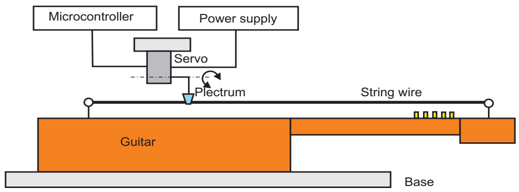


Fig. 3: *Scheme of the strumming actuator experiment.*

Servos have been controlled via using the microcontroller Basic Atom Pro 28-M (fig. 3, fig. 4), which has wide possibilities of servo controlling (parallel controlling of up to 32 servos, hardware controlling servo on background, get servo position, waiting for servo position etc.). Guitar plectrum has been attached to servo horn. Every servo has been controlled for swinging motion in range 30 degree.

Only HS 645MG has been passed in the experiment (fig. 4). Other two servos were not able to make suitable string vibration.

## 4. Pushing of strings

Important role of guitar robot is pushing of strings. Place of string pushing changes generated frequency of tone. Solenoid electromagnetic

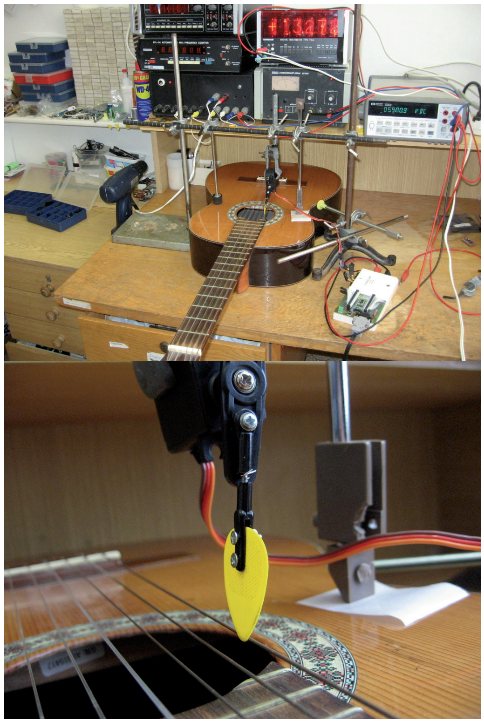

Fig. 4: *Strumming experiments with actuators.*

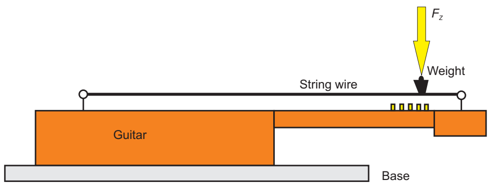


Fig. 5: *Pushing force experiment.*

actuator has been selected for this purpose. Next experiment gives the information about the value of pushing force. This value is necessary for solenoid actuator design.

Etalon weights were used for identification of pushing force. Experiment showed that minimum force is 5N for pushing of string with maximum stiffness *(maximum string diameter).*

Solenoid electromagnetic actuator force (fig. 6) is defined with equation:

$$F_A = \frac{F_m^2 \cdot \mu_0 \cdot A_C}{2 \cdot d_{GAP}^2} \qquad (4)$$

where: $F_A$ – solenoid force (N), $N$ – numebr of turns in coil, $I_C$ – current through the coil (A), $A_C$ – area of coil core (mm$^2$), $d_{GAP}$ – air gap between the core and yoke of coil (mm).

The maximum distance between the spring wire and guitar sleeper is 5 mm. It means that maximum stroke of electromagnetic actuator should be 5 mm. Air gap will be adjusted to 5 mm via using the adjusting screw (fig. 6).

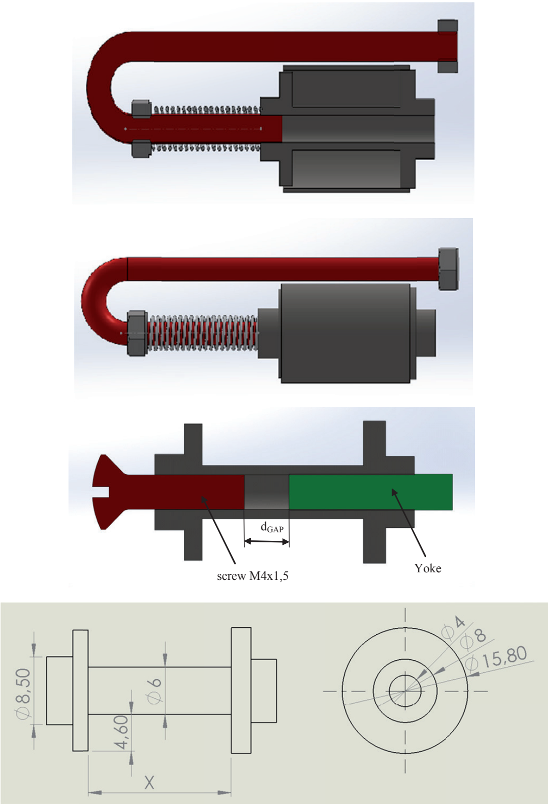


**Fig. 6:** *Designed solenoid electromagnetic actuator.*

On the base of approximate calculation using the equation 1 have made several various test coils (fig. 7) for solenoid actuator. Parameter X (fig. 6) was changed for every tested piece. The maximum distance between the spring wire and guitar sleeper is 5 mm. It means that maximum stroke of electromagnetic actuator should be 5 mm.

Designed actuator with experimental coil has been tested in measuring stand (fig. 8). Measured parameters were pushing force and heating of the coil. The best results were obtained from experiments with last coil (fig. 7), which has the biggest length. This coil has minimum heating and has maximum pushing force. Excitation current was 3A.

Guitar robot will consist of 36 pieces of solenoid actuator arranged on guitar on fixed positions

**Fig. 7:** *Experimental coils for string pushing actuator.*

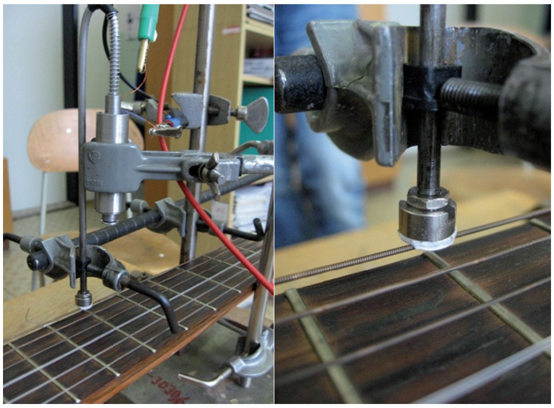

**Fig. 8:** *Testing of solenoid actuator for pushing of the spring wire.*

(fig. 9).Coil Yoke is loaded with combination of eccentric pressure and bending and it has been checked via using the finite element method (FEM) (fig. 10). The maximum stress in coil yoke has value 8 MPa and maximum deformation is less than 0.05 mm.

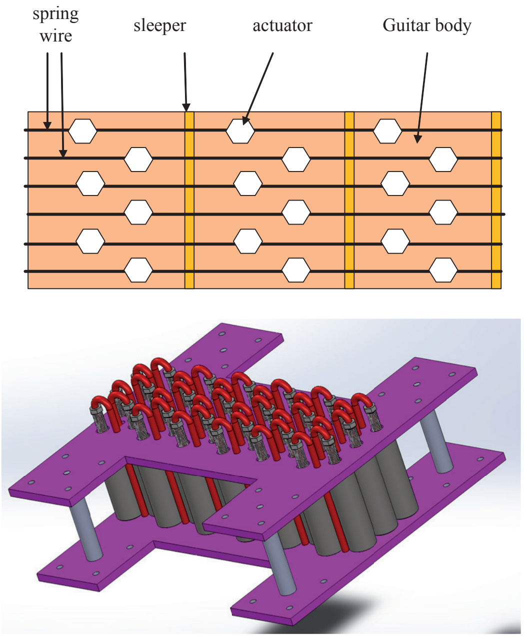


**Fig. 9:** *Solenoid actuators placement on guitar.*

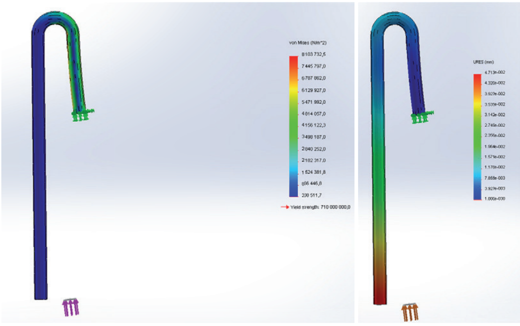

Fig. 10: *FEM of actuator yoke.*

## 5. Overall arrangement

Overall design is shown on figure 11. The arrangement allows playing of much complicated songs because the every string has independent servo with guitar plectrum and also there are 36 pieces of solenoids. All these possibilities overcome the human fingers. All these actuators can be controlled via using the microcontroller or other control system.

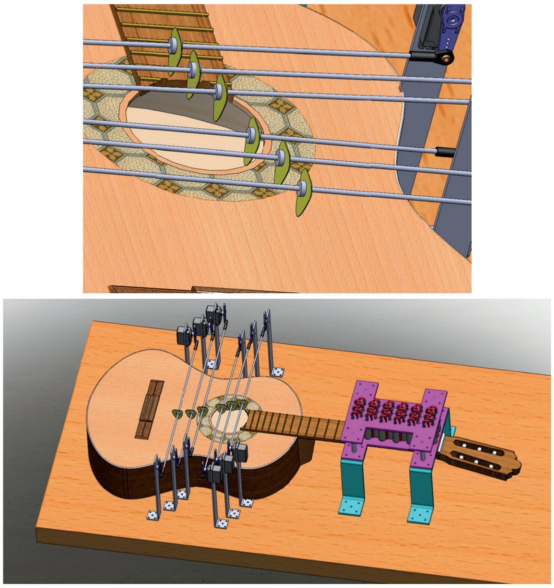

Fig. 11: *Overall arrangement design of guitar robot.*

## 6. Conclusions

The proposed robot is not for commercial use. It is designed as didactic tool for subjects as microcontroller or embedded systems. Other problems, which is not solved up this moment is algorithm of song coding to actuators commands. This didactic tool help to students understand of basic principles of actuators and exciting of them via using of embedded systems. It will help to develop knowledge, skills and experiences of our students.


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