Characterization of Overstress Conditions in Servomotors Employing the Fourier Transform Analysis for Fault-Tolerant Applications

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ABSTRACT

Servomotors are devices commonly utilized in motion generation and position control. Such devices have become preferred by designers because they provide a reliable and inexpensive solution. One of the main problems associated with servomotors is that they tend to burnout if the system in overloaded. This research focuses on developing a low cost, highly reliable solution to this problem. A magnetic field sensor was employed to acquire information of the electric current flowing through a line powering a servomotor. The data was processed employing a fast Fourier transform in order to identify any possible trends that could assist identifying overload conditions. Two different states were tested and compared to judge whether they represent normal operation or overstress conditions. The characterized overstress frequency was utilized to conceptualize a design that will provide fault-tolerant alternatives for mechanical systems that employ servomotors.

Keywords

Servomotors, Overstress, Fault Tolerance.

1. INTRODUCTION

Servomotors are electro-mechanical devices widely employed for many applications. A generic servomotor is composed of a DC electrical motor, and a position sensor (commonly a potentiometer) which provides feedback to a controller. Servomotors are employed in applications ranging from industrial systems to space exploration. Mainly, servomotors are preferred due to their high reliability and low cost, proportioning an appropriate solution for motion generation and position control in mechanical systems.

When a preset position is intended to be reached with the servomotor, a controller will provide an electric current or pulse to the electric motor. Furthermore, the potentiometer will serve as reference for the controller. Once the desired position has been reached, the controller will stop sending electric current to the servomotor.

A critical problem arises when an unexpected obstacle interferes with the rotation of the servomotor, causing it to overstress. When a servomotor undergoes overloading conditions, it may burnout if the current flow is not sopped, or the obstacle removed promptly.

Burnout due to overloading is one of the most common causes of failure in servomotors. Once the servomotor has burned out, the remaining solution is to replace it. Replacing a burned-out servomotor can be an expensive operation, not only because of the relatively high cost of technical service, but for the losses due to downtime. In some cases, the servomotor can be remotely located, which makes the replacement more difficult, causing the system to fail permanently. Thus, prevention of burnout failure effectively becomes extremely important for a system relying on servomotors.

Previously, engineers have attempted to solve the overstress problem. Prior work has employed an encoder embedded in some servomotors to monitor the system. This method allowed engineers to obtain information about the servomotor's running speed when performing statistical calculations to analyze the data from the encoder. This method was particularly implemented for servomotors located in copier machines [1]. The previously described system was able to provide information to facilitate the prevention of failure. Nonetheless, it relays on the embedded encoder that is not always available for every servomotor; furthermore, its design was tailored for a copier machine setting.

Another concept developed to identify possible failure in servomotors is to monitor the electric current supplied to the device. Previous research developed a circuit that filtered a signal in order to monitor the current flowing through a servomotor. Subsequently, the signal was compared with a threshold value. If the current's threshold value were exceeded, the circuit would send a stopping signal to the servomotor. This circuit was designed to stop servomotors once they reach their maximum turning angle. The main purpose was to eliminate the presence of switches to provide feedback when the travel limits are reached [2].

Monitoring the electric current of a servomotor is a concept that has been further developed for applications such as tool breakage detection for small diameter drills. Prior research has employed a wavelet transform while monitoring the current flowing through an AC electric motor in order to provide an online analysis tool to identify failure [3].

The principal motivation for this research is to find an inexpensive and reliable solution to failure due to overstress in servomotors. The electric current flowing through the power line feeding the servomotor is monitored employing a magnetic field sensor. Once the signal from the magnetic field sensor is acquired, it is analyzed employing a fast Fourier transform. Two different conditions are tested. A condition where the servomotor is operating uneventfully is contrasted to a condition where the servomotor is overloaded. A subsystem monitoring a possible burnout of the servomotor will transform the mechanical system into a more robust configuration. Robustness is an important aspect for a system, and the proposed method will improve fault tolerance of a system by detecting failing actuators before they actually fail. This will allow the user to take appropriate alternate action(s) to prevent a failure or a disaster.

2. METHOD

A fast Fourier transform is not s simple calculation; it requires hardware with good computational capabilities, and an efficient algorithm that minimizes the computing time. A computer with Matlab was employed for this experiment. Matlab is a powerful software used to perform a wide variety of mathematical analysis. Matlab possesses a module or toolbox called Simulink. This module facilitates the simulation of several systems by representing them as block diagrams, in which the different parameters can vary.

The servomotor requires a microcontroller to operate properly. In this experiment, a *Basic Stamp 2* microcontroller was programmed to continuously send pulses to the servomotor for about 10 seconds. The pulses will command the servomotor to rotate slowly.

A magnetic field sensor, similar to the ones found in VCRs is employed to acquire information about the current flowing through a cable powering the servomotor. This type of magnetic sensor was selected because it is inexpensive, and available to buy in different electronics stores.

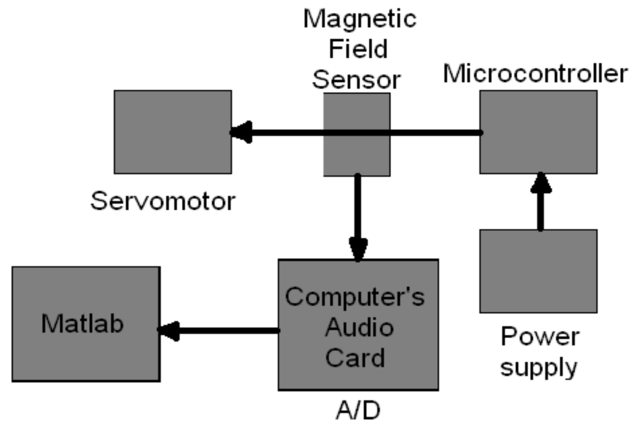

Figure 1. Experimental scheme

Thus, the microcontroller is connected to the servomotor and the magnetic field sensor is placed (wind up) next to the cable powering the servo. The readings generated by the magnetic field sensor are an analog signal. In order to perform the analysis the analog signal has to be converted to a digital signal. Therefore, the magnetic field sensor is connected to the computer through the microphone jack. Matlab possesses a tool that utilizes the audio card of a computer as an analog to digital converter. After the conversion, the digitalized signal is imported into Matlab. Matlab performs the fast Fourier transform and generates plots of the results.

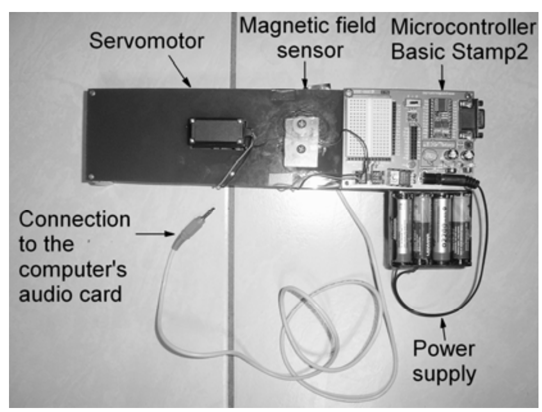

Figure 2. Experiment setup

The *Basic Stamp 2* microcontroller is programmed employing the PBasic Compiler. This compiler possesses some built-in functions that facilitate the operation of microcontrollers. For instance, the function PULSEOUT generates a PWM command to increment the angle of the servomotor slowly. The range of this particular servomotor is 180^{o}. Every time a pulse is emitted by the microcontroller, the electric current will generate a magnetic field while traveling along the wire or power line, the magnitude of this magnetic field will be recorded by the magnetic field sensor.

The code employed to generate the PWM Command was generated as follows:

```
' {$STAMP BS2}
' {$PBASIC 2.5}
reps VAR Byte
Main:
 FOR reps = 200 TO 1700 STEP 10
    PULSOUT 12, reps
    PAUSE 10
 NEXT
END
```

A block diagram was sketched employing Simulink, as shown in Figure 3. The block diagram displays the different functions applied to se signal acquired from the magnetic field sensor. Different samples are obtained from the same dataset. First, the data is filtered in order to reduce any possible noise. Then, the Fast Fourier transform is applied, and subsequently the Inverse Fourier transform is obtained as well. When performing the experiment, the simulation was first employed without the filter in order to estimate where the frequency of interest is lying. Once a range is narrowed, the filter could be designed and the experiment performed again.

A Matlab-scrip enabling the analog to digital conversion through the computer's audio card was employed as follows.

3. DATA AND RESULTS

Matlab generated a series of plots based on the data acquired and the fast Fourier transform analysis. The first plot presented in Figure 4 displays the result of the conversion from analog to digital of the magnetic field sensor reading as a function of time. This plot corresponds to the condition where the servomotor is operating uneventfully.

```
%% Example data acquisition session
% This demonstration shows the procedure for acquiring data.
% This demo requires the Data Acquisition Toolbox

%% Create object
% Specify the type of communication (analog input) and the hardware
vendor.
ai = analoginput('winsound');       % Create
chan = addchannel(ai,1);                   % Add channel

%% Configure
% Look at the object.
ai             %#ok High level summary
get(ai)        % Detailed property list

%%
% Set the analog input parameters
set(ai, 'SampleRate', 44100);       %Configure
set(ai, 'SamplesPerTrigger', 44100*10);       %Configure

%% Start
start(ai)

%% Read data
% With just a few lines of MATLAB code, we now have our data in MATLAB
[data,time]=getdata(ai);
plot(time,data);


%% Disconnect / Clean up
% The last step is to disconnect MATLAB from the hardware.
delete(ai)
clear ai chan
```

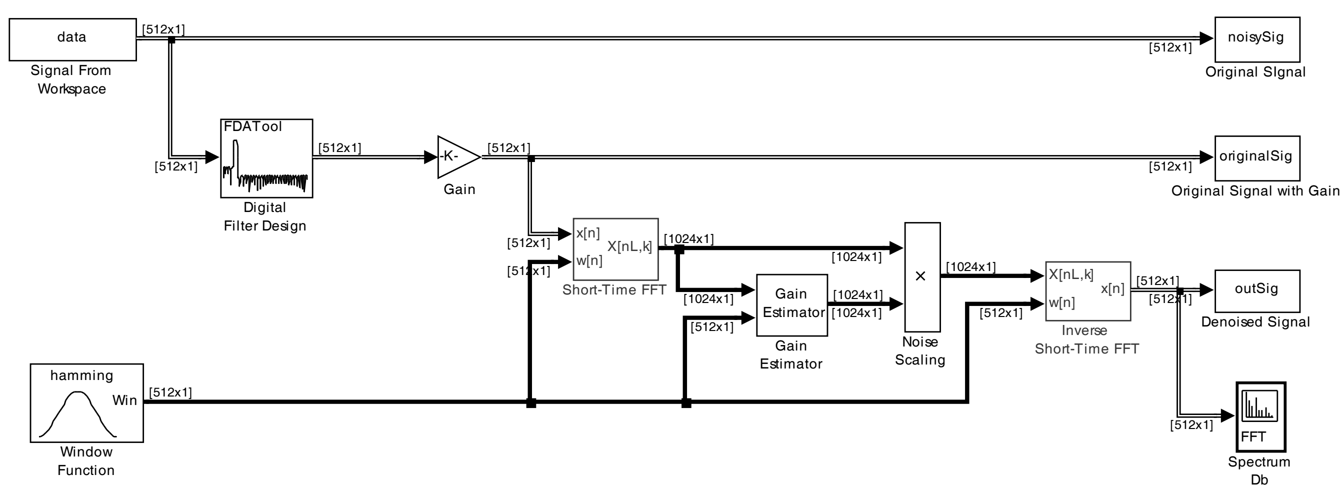

Figure 3. Block diagram for data processing

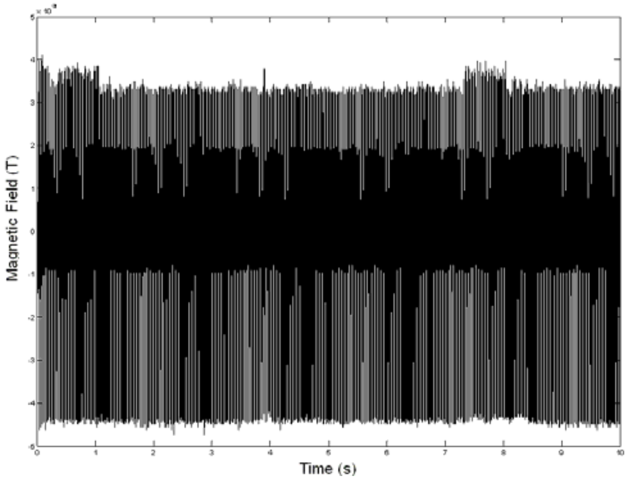

Figure 4. Data acquired when the servomotor was operating in normal conditions

In contrast, a plot of the result from the analog to digital conversion of the magnetic fields sensor versus time; when the servomotor is prompted with an object and therefore undergoing overstress conditions is presented in Figure 5.

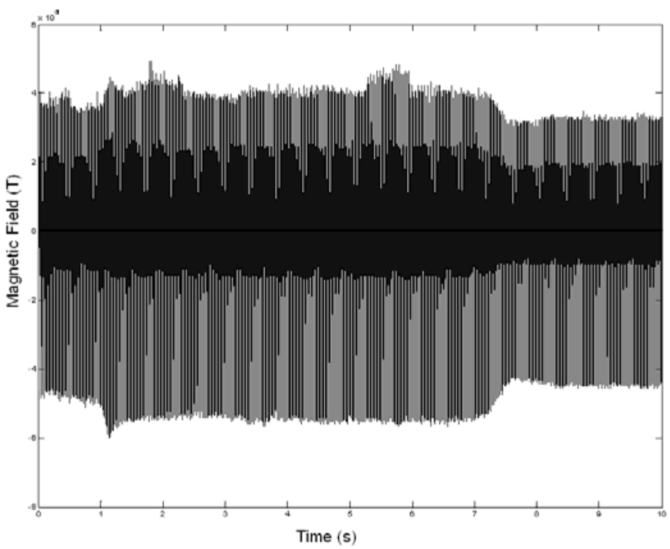

Figure 5. Data acquired when the servomotor was undergoing overstress conditions

Once the Fourier transform analysis is executed by Matlab, the result is displayed in a periodogram, first for the case in which the servomotor is operating in normal conditions, (Figure 6), and subsequently for the case where the servomotor is overloaded (Figure 7).

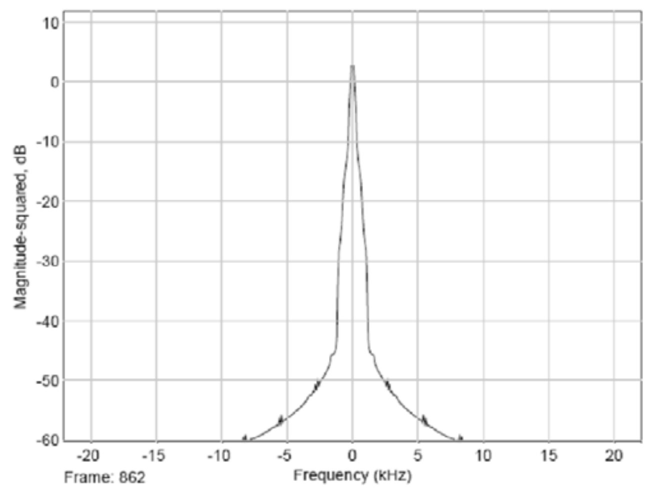

Figure 6. Periodogram displaying the result of the Fast Fourier transform for normal operation conditions

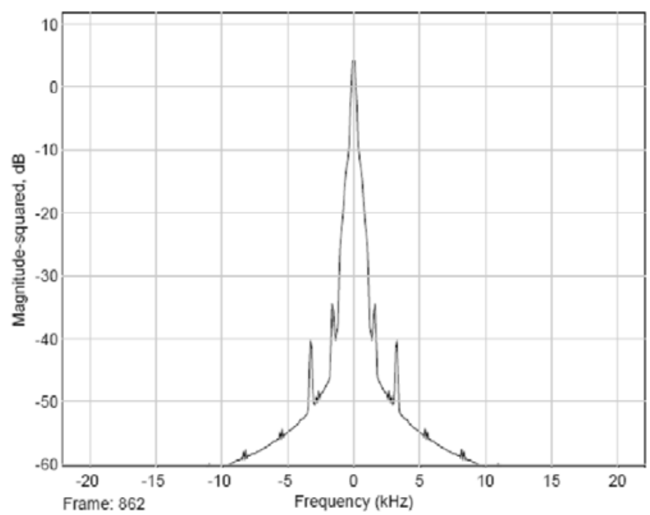

Figure 7. Periodogram displaying the result of the Fast Fourier transform for overstress conditions

It is possible to visually identify that the main difference in the periodograms is approximately located at 3 kHz. Thus, a filter is applied to obtain the value of the frequency at 3 kHz; first for the normal operation condition as shown in Figure 8, and then for the overstressed condition as illustrated in Figure 9.

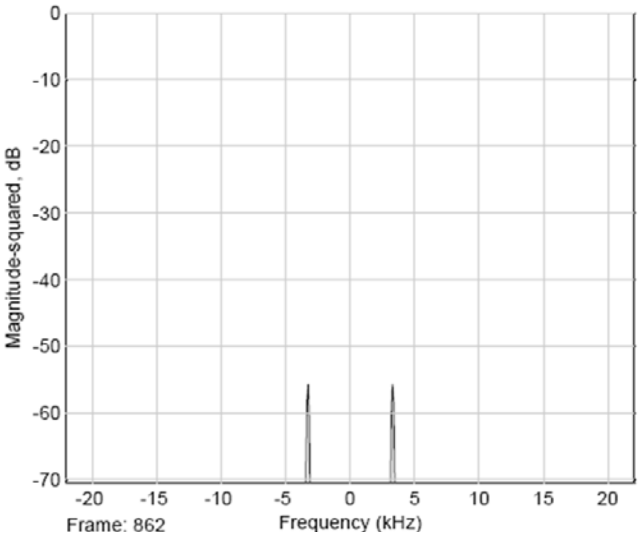

Figure 8. Result of the fast Fourier transform for normal operating conditions at 3 kHz

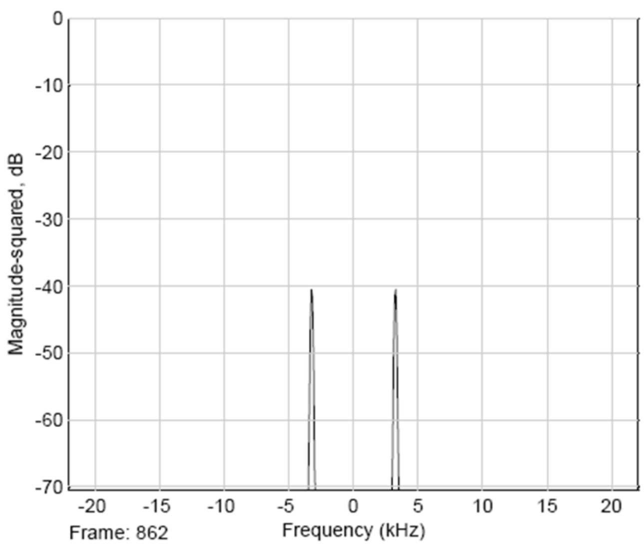

Figure 9. Result of the fast Fourier transform for overstress conditions at 3 kHz

4. DISCUSSION

When the raw data acquired from the magnetic field sensor is inspected, it is possible to observe changes in the magnetic field of the line powering the servomotor. When the microcontroller sends a pulse to the servomotor, it will appear on the graph as a vertical line, for which the magnitude or line length will vary.

In the case where the servomotor is operating in normal conditions, it is possible to establish that the magnitude of the magnetic field created by the pulses remains relatively constant. In contrast, for the case where the servomotor is operating under overloading conditions, it is possible to determine that the amplitude of the signal does not remain constant, and the change shows the characteristics of a step function. The function seems to step up when the servomotor is overloaded, and it steps down once the load is removed.

It is not possible to exclusively determine overstress conditions by visual identification; more information needs to be gathered before any meaningful and more reliable conclusion can be drawn. Furthermore, it will be a difficult task for any system to accurately interpret any plot obtained from the magnetic field sensor. The Fourier transform facilitates the process of identifying a characteristic frequency. It can be thought that when the servomotor is overloaded, the extra current provided in order to move the servomotor is like an extra signal added to the basic signal (current supplied when the servomotor is operating normally). The Fourier transform will decompose the different signals into their frequency components, facilitating the effective characterization of an overstress frequency.

When the electric current is continuously monitored by a magnetic field sensor, this information can provide further insight for the operation of the system. Fault tolerant systems employing this concept can enhance its fault detection capability. It is an advantage that the current is being monitored along the cable powering the servomotor; because the magnetic field sensor does not have to be located near the servomotor; it can be positioned in a more protected place. If the characteristic overstress frequency is identified, and the servomotor is stopped promptly, failure due to overloading will be prevented. Hence, potentially catastrophic failures may be prevented.

Since the magnetic field sensors are inexpensive, the marginal benefit of implementing a system monitoring the current supplied to the servomotor with a magnetic field sensor will widely surpass its marginal cost. Moreover, the inversion costs will be recovered with the money saved from possible downtime caused by the servomotor failure, and from replacing the burned servomotor.

5. CONCLUSION

An interesting conclusion is drawn after performing this experiment. It is possible to conclude that when the electric current supplied to a servomotor is monitored, different operation states of the servomotor can be identified. If the data obtained from the different operating states is decomposed into their frequency components employing a Fourier transform, and then compared, a difference in the frequency spectrum is observed. It is also observed that a characteristic frequency exists when a servomotor undergoes overstress conditions. For the servomotor tested in this experiment, the characteristic frequency is determined to be 3000 Hz. When the servomotor was operating in normal conditions, the magnitude of the Fourier transform for 3000Hz was – 56 db, while the magnitude for the same frequency when the experienced overloading was – 41 db. The difference in magnitude was 15 db. This difference in magnitude can be easily identified and then employed to prevent burnout of the servomotor due to overstress conditions.

6. FUTURE WORK

There are different types of servomotors, mainly varying in size and torque capacity. For the experiments reported in this work, only one servomotor was employed. The next step in this investigation will be to test different types of servomotors to determine if the characteristic overstress frequency remains constant or changes with respect to the servomotor type.

Furthermore, if the characteristic overstress frequency changes, it may be possible to establish a relationship between such frequency and the influencing parameter(s). In general, a larger torque capacity will require a larger electrical current consumption; therefore, particular attention should be placed to the change in torque capacity, because it is possible that the characteristic frequency varies with respect to the torque capacity of the motor.

Once the characteristic frequency has been studied for different servomotors, it will be possible to design a circuit that reads the magnetic field sensor and identifies the overstress condition based on the characteristic frequency. Once the overstress condition is detected, the circuit will send a signal to the microcontroller to stop the current flow through the servomotor and effectively prevent failure.

7. REFERENCES

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