MEASUREMENTS PROJECT

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Abstract:

Key words: Automated stage, LSM, microscope, X-Y linear motor

1. INTRODUCTION

The diagnosis of many diseases, including Tuberculosis (TB) and Malaria, requires the analysis of many sections of a specimen. This system is not perfect as irregularities in the specimen may congregate resulting in an incorrect diagnosis. For an accurate diagnosis, more sections of a specimen need to be analysed. Image recognition software exists to analyse digitised images for patterns, which may represent contaminations. A means of quickly capturing images of a specimen for this computation to be performed is not as common.

To eliminate this bottleneck, an automated stage was developed. Its construction was based on the Olympus BX50 [1] and its automation was provided by an X-Y LSM. The BX50 is fitted with a manual stage and is designed to host a light-weight, compact stage.

The capture rates of existing digital devices influenced the speeds at which the stage moved. Image recognition software requires computer resources, but it was assumed that these facilities may not be available at the microscope station. Therefore the system was to be designed as a standalone system, with optional computer control via an appropriate interface.

Success was based primarily on the achievement of smooth, speed-optimised X-Y linear motion allowing clear images of the specimen to be captured. Thereafter, a standalone, light-weight, compact and efficient design provided measures of success. The designed motorised stage and its drive system are presented. The performance is discussed and an alternative solution presented.

2. BACKGROUND

2.1 Weight measurement systems

The diagnosis of Tuberculosis and Malaria involves the examination of sputum and blood samples respectively [2–4]. These examinations also reveal the contagious quality of infections such as TB. Therefore, faster diagnosis results in better containment of the disease and allows the

Resistive: The six TTL logic level PWM signals formed inputs into a six channel class-D amplifier. This consisted of a primary stage in which comparators, made from TL074 op-amps, pushed the voltage signals to the rails. Thereafter, the same TIP122 and TIP125 complimentary darlington transistor pairs were used in an H-bridge configuration to provide current amplification.

It is typically understood that the armature windings filter Voltage Source Inverter PWM signals to produce smoothed current signals. In reality, the -3 dB frequency of the filter created by the armature windings is given by $f = \frac{R}{2\pi L}$. For the designed armatures, the resultant -3 dB frequencies were 3.183 kHz and 17.683 kHz for the wire-wound and PCB armatures respectively. Therefore, the switching frequency permeated through the armatures as current signals with no attenuation. A six channel filter bank was designed to compensate for this effect. Each channel was a second order RLC filter, as shown in *Figure 1*. The resulting -3 dB frequency was 112 Hz.

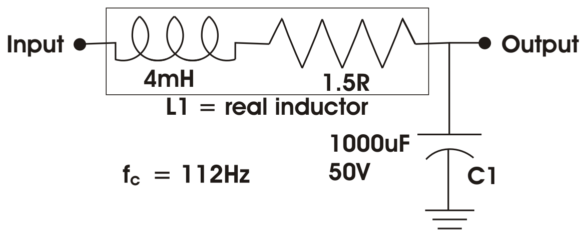

Figure 1 : RLC Filter Circuit

Elastic: The topology employed consisted of an active armature and a passive PM cursor [5]. The advantage of this topology was that the cursor was electrically isolated from the stage such that no electrical contacts were in motion. This increased durability.

where:

v	=	Linear Velocity (mm/s)
v_s	=	Synchronous Linear Velocity (mm/s)
f	=	Input Frequency (Hz)
τ	=	Pole Pitch (mm)

Two armatures were tested. The first design made use of a PCB. The second was a wire-wound armature. The advantages and disadvantages of both are presented in *Table 1* with a final specification given in *Table 2*. The two PM arrays shown in *Figure 4* were also tested. They represent compromises between size and flux linkage.

Pneumatic: To determine the pole-pitch, the speeds required must be considered. From the Olympus BX50's technical data, the observable fields-of-view range between 0.22 mm and 5.5 mm. From this, and the rate of capture of the digital imaging devices, the linear speeds at which this system can move are between 0.176 mm/s and 44 mm/s. This includes a 20% overlap which allows for accurate digital knitting.

Piezoelectric: To achieve these low speeds, minimisation of both the pole-pitch and the input frequencies is essential. The relationship between these three variables is given in *Equation 1*. The pole-pitch was limited by the dimensions of available Nd-Fe-B PM's. The smallest available PM's were 8.6 × 8.6 mm × 3 mm, polarised along their shortest dimension. To minimise force-ripple, the ratio of the magnet-length to the machine pole-pitch is 0.8 [6]. This ratio results in reduced harmonics in the DC magnetic field and lower thrust, but is essential for smooth motion. Therefore, the system pole-pitch was 10.75 mm and the excitation frequencies needed to be between 0.008 Hz and 2 Hz.

$$v = v_s = 2f\tau \tag{1}$$

3. SYSTEM OVERVIEW

A microscope stage is required to move along all three axes. The vertical motion of the stage provides a focusing mechanism and is usually performed by moving the stage mounting system vertically. The specimen is then moved in the X-Y plane, about the optical centre of the microscope stage, exposing any point of the specimen to the viewer. On the Olympus BX50, this motion is provided by two concentric rotary dials.

4. MODELLING

The Olympus BX-50 has adopted standard photomicrography camera lenses, namely C- and CS-mounted lenses [1]. The capture rate of available digital capture devices range between 1/60 fps, from still cameras, to 30 fps, from video cameras using the National Television Standards Committee (NTSC) system [1].

4.1 Sensing Element

LSM's have come into favour because of [7, 8]:

1. Their accurate positioning capabilities via DC excitation.
2. The lower cost and weight of permanent magnet (PM) movers which do not require power supplies
3. The high thrusts, speeds and efficiencies they can provide.
4. The absence of a transmission which eliminates gearing losses, and increases reliability and dynamic performance.

4.2 Signal Conditioning

Figure 2 : System Overview

Figure 2 depicts the three sections of the designed system.

The dsPIC30F6014 MCU [9] was used to control the motor. In the case of sinusoidal power signals, it presented digital signals to two digital-to-analog converters (DAC). For the application of PWM power signals, six output-compare channels were used.

4.3 Signal Processing

Two 12-bit DAC's produced the A and C phases for both directions. A sequence of inverting summing amplifiers generated the third phase from the redundancy in three-phase systems, and provided bipolar operation. Six Class-AB power amplifiers provided the current necessary to drive the X-Y LSM.

4.4 Data Communication

A six channel class-D amplifier provided the current necessary to drive the X-Y LSM through a filter bank. The filter bank was developed to compensate for the armature's low filtering ability.

The armature windings were based on two flat, stacked, orthogonal LSM's as described by Davies [10], providing independent two-dimensional movement.

5. SYSTEM ANALYSIS

The LSM was a single sided design, employed to minimise the height of the system. The disadvantage of this design was that less flux was generated [5]. A back iron was also neglected because of the associated weight which could not be accommodated by the stage support. This reduced flux linkage.

5.1 Static Properties

Resolution: The layout specified by Davies [10] was scaled for use in this application. The LSM's orthogonal placement provided independent motion along two dimensions because of the associated orthogonal magnetic fields and theoretical zero mutual inductance.

The disadvantage of this layout was that the individual LSM's were at different depths from the cursor. The result was that, at the level of the PM array, the lower LSM produced a weaker magnetic field than the upper LSM.

Range: The armature was a slotless design. Although the magnetic field was weaker in this design, the detent forces were eliminated [6, 8]. Detent forces are the periodic attractive forces between the PM's and the metallic slots between the windings. In order to achieve smooth motion, these forces must be eliminated.

Table 2 : Motor Specifications

	Specification	Value (Units)
1.	3Φ Connection	Δ
2.	Pole Pairs	6×6
3.	Pole Pitch	10.75×10.75 (mm)
4.	PCB Track Width	0.695 (mm)
5.	PCB Series-Turns/Phase	24×24
6.	Wire-Wound wire ⊘	0.35 (mm)
7.	Wire-Wound Series-Turns/Phase	180×180
8.	Max Current	1.5 (A)
9.	Nd-Fe-B PM Size	8.6×8.6×3 (mm)

System Error:

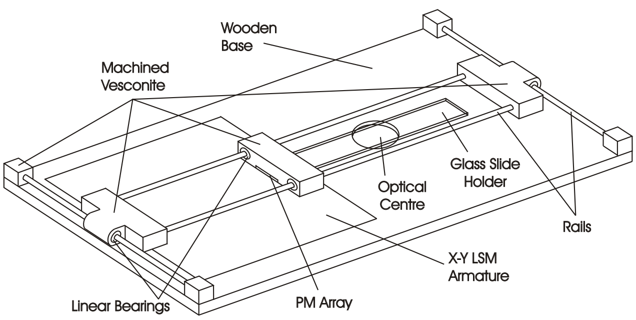

Figure 3 : Stage Design

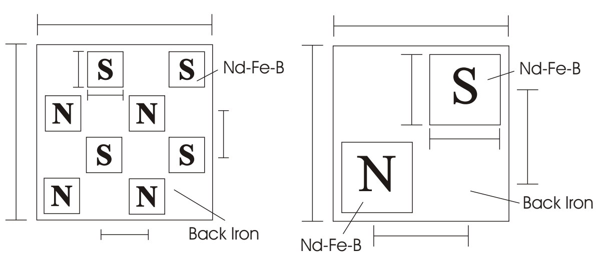

Figure 4 : PM Array Configurations

5.2 Dynamic properties

The dsPIC MCU was used to generate the six phase signals required to drive both dimensions of the X-Y LSM. The program strategy was designed according to a layered system. The signal generation formed the lowest level of the structure and accepted two inputs, the X- and Y-direction frequencies, called the frequency bus. Subsequent layers existed separately from the generation layer. To control the LSM, a layer asserted a value onto the frequency bus. This provided a means of stacking various layers such as a joystick or RS-232 controller layer.

The two 12-bit digital buses were connected to two Maxim MX7847BN DAC's. Channel A of the two DAC's produced phases A and C for the X-direction whilst Channel B produced the same for the Y-Direction. Bipolar operation was achieved using inverting, summing, operational amplifier configurations according to the application notes. For each direction, phases A and C were summed in an inverting configuration to produce phase B according to *Equation 2.* Tuning potentiometers were set to within 0.2% fullscale (FS) to achieve phase and amplitude symmetry. The six phase signals formed inputs to the six current gain amplifiers. These were class-AB power amplifier configurations using TIP122 and TIP125 complimentary darlington transistor pairs. They could be driven directly from the TL074 op-amps because of their high current gain ($H_{fe-min} = 1000$). This eliminated excessive external circuitry. A TL074 op-amp was used to ensure accurate amplification by placing the class-AB amplifier in the feedback loop of the op-amp, with a buffered input to the op-amp. The six outputs were connected directly to the X-Y LSM windings.

$$\begin{aligned} i_A + i_B + i_C &= 0 \\ i_B &= -i_A - i_C \end{aligned} \tag{2}$$

6. CONCLUSION

Slow and smooth motion necessary for the automation of specimen photomicrography could not be achieved due to torsional effects introduced when only two X-Y linear synchronous motors were used to automate an electric microscope stage. To resolve this problem, it is recommended that a layout using four independent linear synchronous motors be implemented.

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Table 1 : Armature Advantages and Disadvantages

	Advantages	**Disadvantages**
PCB	1) The thin armature reduced leakage flux and eliminated LSM vertical separation. 2) The pole-pitch was exactly matched.	1) 24 series-turns/phase; costly to increase 2) High Cost (R3 000)
Wire-Wound	1) Low Cost (R200) 2) 180 series-turns/phase 3) Well matched pole-pitch	1) Thicker armature increased leakage flux and imposed vertical LSM separation. 2) Timely construction procedure.

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