UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

MSC SYSTEMS ENGINEERING AND ENGINEERING MANAGEMENT

SEMESTER TWO EXAMINATION 2018/2019

MONITORING OF MECHANICAL SYSTEMS

MODULE NO: EEM7018

Date: Thursday 23rd May 2019 **Time: 14:00 – 16:00**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

Answer ANY THREE questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

All working must be shown. A numerical solution to a question obtained by programming an electronic calculator will not be accepted.

The typical properties of piezo film is given at the end of the paper in Table 1.

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Q1. (a) Critically discuss the strategic importance of maintenance for an organisation. **(7 marks)**

(b) Identify three commonly used traditional maintenance policies in the mechanical systems and justify their applications. **(6 marks)**

(c) Explain the techniques and main features of Machine Condition Monitoring (MCM), Identify with the aid of block diagrams the basic elements of a modern Machine Condition Monitoring (MCM) system, and Provide an example for using MCM technology in industry. **(12 marks)**

Total 25 marks

Q2. (a) Explain the basic elements involved in a vibration diagnosis system. **(4 marks)**

(b) Figure Q2(b) shows a CNC machine centre.

(i) Identify and briefly explain 4 vibration sources on the CNC machine centre. **(4 marks)**

(ii) Discuss the possible effects caused by vibrations on CNC machine centre. **(5 marks)**

(iii) For each vibration source identified from (i) above, suggest possible vibration measurement techniques, which should include the sensor/transducer systems selection, signal processing, and data analysis. **(12 marks)**

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Question 2 continued….

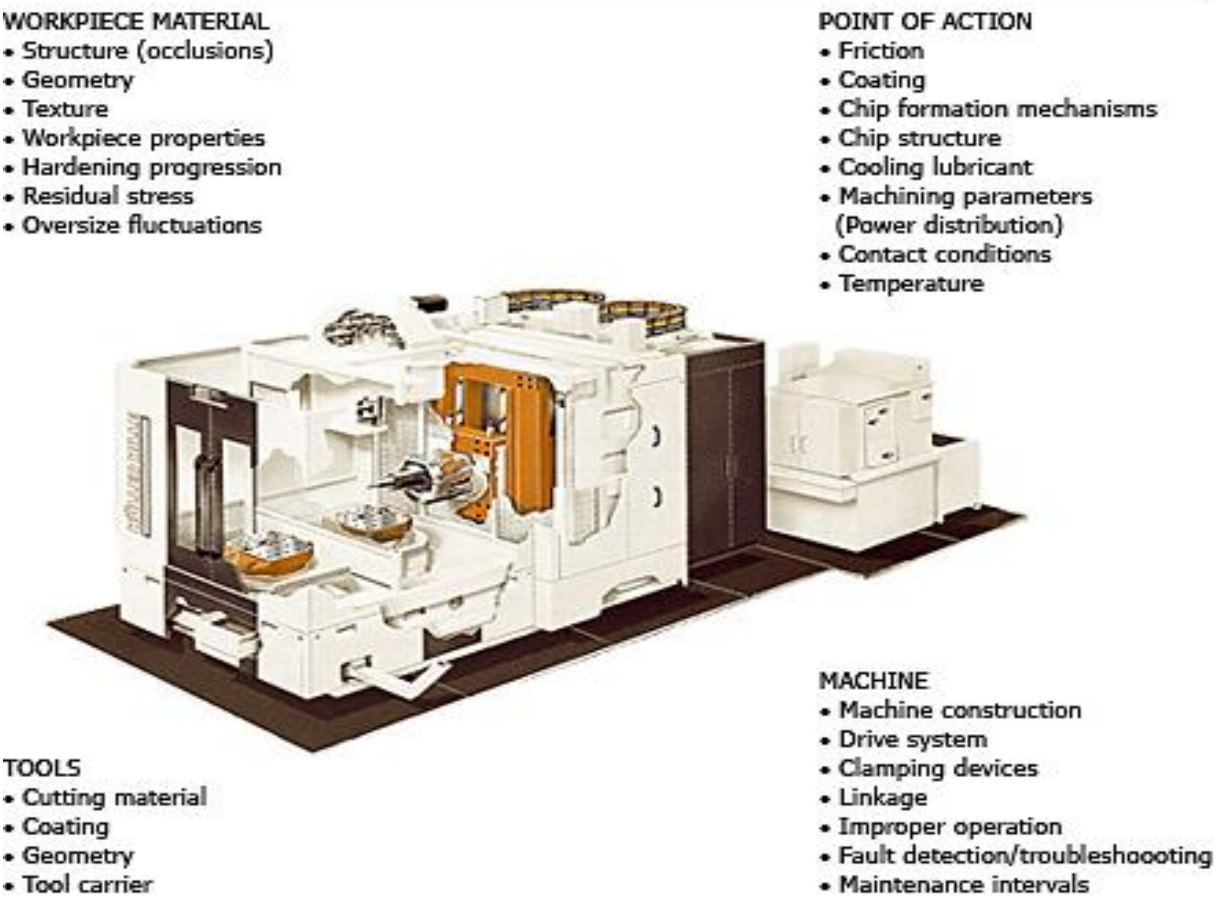

Figure Q2(b) A CNC Machine Centre

Total 25 marks

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Q3.

(a) Describe the operation of a MEMS accelerometer. **(6 marks)**

(b) Draw the equivalent circuit of a piezo film sensor as a voltage source. Describe the electrical properties of the model. **(6 marks)**

(c) A 2.35 psi load is applied to a PVDF piezo film switch of 2.75 cm length, 3.25 cm width and 225 μm in film thickness. The switch element is rigidly backed, so the force acts to compress the film's thickness. Therefore, the piezo film works at g_{33} mode.

Please calculate the voltage developed across the piezo film. The typical properties of the piezo film are given in Table 3 at the back of this paper, and the conversion factor from psi to N/m^2 is approximately 7,000.

(5 marks)

(d) Operational amplifiers are commonly used to amplify the weak signals collected from the sensors. Non-inverting amplifier & inverting amplifier are the two most common amplifier circuits. Draw the circuits for both types of operational amplifiers and design the Op-amp circuits with the amplification of 50 and -50, respectively. **(8 marks)**

Total 25 marks

Q4.

(a) What unexpected side effect will cause when an analogue signal is not sampled at an appropriate rate?

(2 marks)

(b) Please calculating the apparent frequencies (f_a) of the following analog signals with the given sample rates and determine the minimum appropriate sampling frequencies to avoid the side effect.

(i) $y(t) = 5\cos(1700\pi t+20)$, sample rate Fs = 1000 Hz **(4 marks)**
(ii) $y(t) = 20\sin(630\pi t-3)$, sample rate Fs= 400Hz **(4 marks)**

(c) What is Fourier transform commonly used for in the signal processing area? Please give an example of the application of the Fourier transform in the mechanical system monitoring field. **(4 marks)**

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Question 4 continued….

(d) A digital filter has the following difference equation:

$$y_n = 0.7x_n - 0.3x_{n-1} + 0.1y_{n-1} - 0.4y_{n-2}$$

(i) State whether the given filter is a recursive or non-recursive filter and explain the difference between them. **(4 marks)**

(ii) What is the order of the given filter? Why? **(2 marks)**

(iii) The following sequence of input values is applied to the filter: $x_0=4$, $x_1=8$, $x_2=2$, $x_3=11$, $x_4=3$, $x_5=1$. Determine the output sequence for the filter from y1 to y3.

(5 marks)

Total 25 marks

Q5. A block diagram for an analogue control system is shown in **Figure Q5** below:

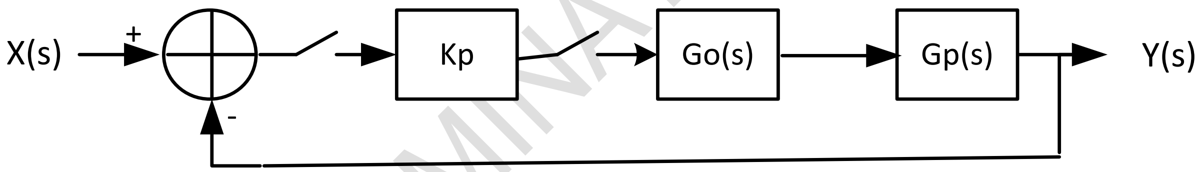

Figure Q5

Where the digital controller is Kp,

and the zero-order hold $G_0(s) = \frac{1-e^{-sT}}{s}$,

with the plant $G_P(s) = \frac{0.5}{s+0.5}$

(a) Determine the closed **-** loop digital z transfer function for the system. **(10 marks)**

(b) If the gain of the digital controller Kp = 10, determine the range of the sampling interval T that will make the closed loop stable. **(7 marks)**

(c) If the sampling frequency f = 20Hz, determine the range of the controller gain Kp which will make the closed loop stable. **(8 marks)**

Total 25 marks

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Q6 (a) When describing an OP-Amp, what is meant by the terms of:

Common - mode rejection ratio, and

Slew rate and transition frequency. **(6 marks)**

(b) For the circuit shown in **Figure Q6** calculate the output voltage.

(10 marks)

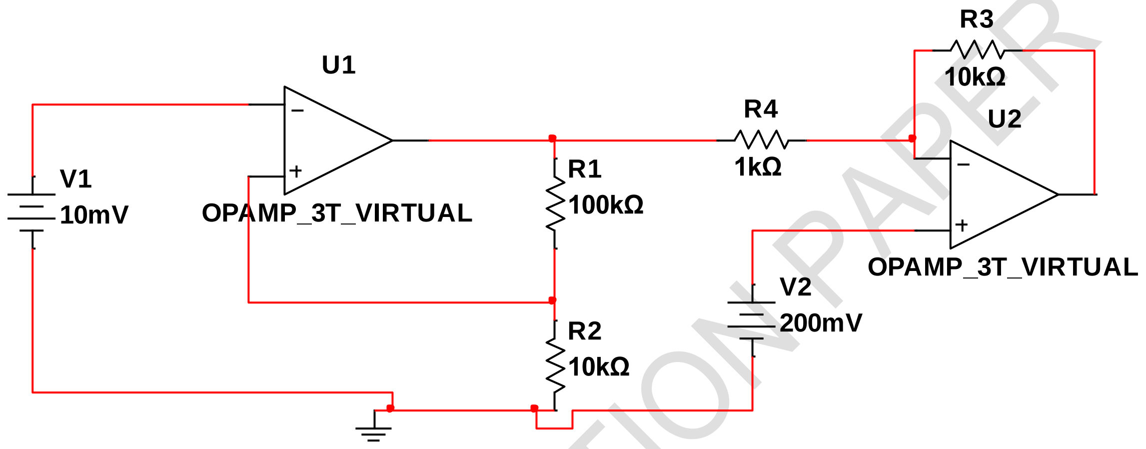

Figure Q6

(c) A low-pass active filter is shown in **Figure Q7**, derive the transfer function, calculate the closed loop gain, and corner frequency**.**

(9 marks)

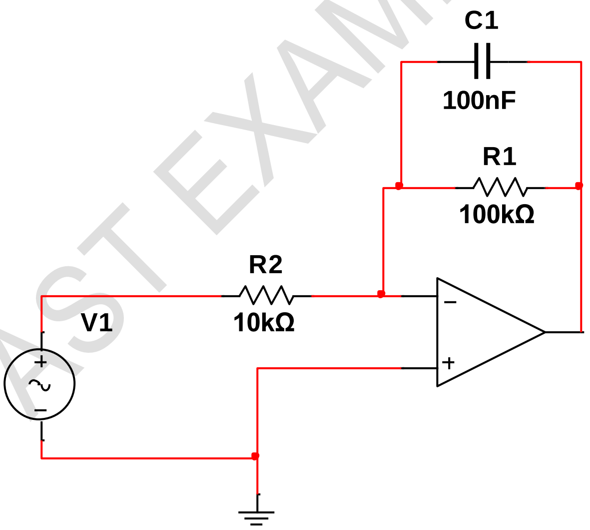

Figure Q7

Total 25 marks

END OF QUESTIONS

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Table 1 of Basic Laplace and Z transforms

Time f (t)	Laplace F(s)	Z transforms
1. $\delta[t]$	1	1
2. $u(t)$	$\frac{1}{s}$	$\frac{z}{z-1}$
3. t	$\frac{1}{s^2}$	$\frac{Tz}{(z-1)^2}$
4. e^{-at}	$\frac{1}{s+a}$	$\frac{Z}{Z-e^{-aT}}$
5. $\frac{1}{a(1-e^{-at})}$	$\frac{1}{s(s+a)}$	$\frac{z(1-e^{-aT})}{a(z-1)(z-e^{-aT})}$
6. $\sin\omega t$	$\frac{\omega}{s^2+\omega^2}$	$\frac{z\sin\omega T}{z^2-2z\cos\omega T+1}$
7. $\cos\omega t$	$\frac{s}{s^2+\omega^2}$	$\frac{z^2-z\cos\omega T}{z^2-2z\cos\omega T+1}$
8. $e^{-at}\sin\omega t$	$\frac{\omega}{(s+a)^2+\omega^2}$	$\frac{ze^{-aT}\sin\omega T}{z^2-2ze^{-aT}\cos\omega T+e^{-2aT}}$
9. $e^{-at}\cos\omega t$	$\frac{s+a}{(s+a)^2+\omega^2}$	$\frac{z(z-e^{-aT}\cos\omega T)}{z^2-2ze^{-aT}\cos\omega T+e^{-2aT}}$
10. $\sinh\omega t$	$\frac{\omega}{s^2-\omega^2}$	$\frac{z\sinh\omega T}{z^2-2z\cosh\omega T+1}$
11. $\cosh\omega t$	$\frac{s}{s^2-\omega^2}$	$\frac{z(z-\cosh\omega T)}{z^2-2z\cosh\omega T+1}$

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Table 2 of Basic Sampled data and Z Transforms

signal x[n]	z Transform X(z)	Region of Convergence
1 $\delta[n]$	1	all z
2 $u[n]$	$\frac{z}{z-1}$	$\lvert z \rvert > 1$
3 $\beta^n u[n]$	$\frac{z}{z-\beta}$	$\lvert z \rvert > \lvert \beta \rvert$
4 $nu[n]$	$\frac{z}{(z-1)^2}$	$\lvert z \rvert > 1$
5 $\cos(n\Omega)u[n]$	$\frac{z^2 - z\cos\Omega}{z^2 - 2z\cos\Omega + 1}$	$\lvert z \rvert > 1$
6. $\sin(n\Omega)u[n]$	$\frac{z\sin\Omega}{z^2 - 2z\cos\Omega + 1}$	$\lvert z \rvert > 1$
7 $\beta^n \cos(n\Omega)u[n]$	$\frac{z^2 - \beta z\cos\Omega}{z^2 - 2\beta z\cos\Omega + \beta^2}$	$\lvert z \rvert > \lvert \beta \rvert$
8 $\beta^n \sin(n\Omega)u[n]$	$\frac{\beta z\sin\Omega}{z^2 - 2\beta z\cos\Omega + \beta^2}$	$\lvert z \rvert > \lvert \beta \rvert$

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Table 3. Typical properties of piezo film

Symbol	Parameter	PVDF	Copolymer	Units
t	Thickness	9, 28, 52, 110	<1 to 1200	μm (micron, 10^{-6})
d_{31}	Piezo Strain Constant	23	11	10^{-12} $\frac{m/m}{V/m}$ *or* $\frac{C/m^2}{N/m^2}$
d_{33}		-33	-38	
g_{31}	Piezo Stress constant	216	162	10^{-3} $\frac{V/m}{N/m^2}$ or $\frac{m/m}{C/m^2}$
g_{33}		-330	-542	
k_{31}	Electromechanical Coupling Factor	12%	20%	
k_t		14%	25-29%	
C	Capacitance	380 for 28μm	68 for 100μm	pF/cm^2 @ 1KHz
Y	Young's Modulus	2-4	3-5	10^9 N/m^2
V_0	Speed of Sound — stretch:	1.5	2.3	10^3 m/s
	thickness:	2.2	2.4	
p	Pyroelectric Coefficient	30	40	10^{-6} C/m^2 °K
ε	Permittivity	106-113	65-75	10^{-12} F/m
$ε/ε_0$	Relative Permittivity	12-13	7-8	
$ρ_m$	Mass Density	1.78	1.82	10^3kg/m
$ρ_e$	Volume Resistivity	$>10^{13}$	$>10^{14}$	Ohm meters
$R_□$	Surface Metallization Resistivity	<3.0	<3.0	Ohms/square for NiAl
$R_□$		0.1	0.1	Ohms/square for Ag Ink
tan $δ_e$	Loss Tangent	0.02	0.015	@ 1KHz
	Yield Strength	45-55	20-30	10^6 N/m^2 (stretch axis)
	Temperature Range	-40 to 80...100	-40 to 115...145	°C
	Water Absorption	<0.02	<0.02	% H_2O
	Maximum Operating Voltage	750 (30)	750 (30)	V/mil(V/μm), DC, @ 25°C
	Breakdown Voltage	2000 (80)	2000 (80)	V/mil(V/μm), DC, @ 25°C

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Table 4 trigonometric equations

$\sin(\alpha+\beta) = \sin\alpha\cos\beta + \cos\alpha\sin\beta$ $\sin(\alpha-\beta) = \sin\alpha\cos\beta - \cos\alpha\sin\beta$ $\cos(\alpha+\beta) = \cos\alpha\cos\beta - \sin\alpha\sin\beta$ $\cos(\alpha-\beta) = \cos\alpha\cos\beta + \sin\alpha\sin\beta$	$\tan(\alpha+\beta) = \frac{\tan\alpha + \tan\beta}{1-\tan\alpha\tan\beta}$ $\tan(\alpha-\beta) = \frac{\tan\alpha - \tan\beta}{1+\tan\alpha\tan\beta}$
$\sin\alpha + \sin\beta = 2\sin\left(\frac{\alpha+\beta}{2}\right)\cos\left(\frac{\alpha-\beta}{2}\right)$ $\sin\alpha - \sin\beta = 2\cos\left(\frac{\alpha+\beta}{2}\right)\sin\left(\frac{\alpha-\beta}{2}\right)$	$\cos\alpha + \cos\beta = 2\cos\left(\frac{\alpha+\beta}{2}\right)\cos\left(\frac{\alpha-\beta}{2}\right)$ $\cos\alpha - \cos\beta = -2\sin\left(\frac{\alpha+\beta}{2}\right)\sin\left(\frac{\alpha-\beta}{2}\right)$
$\sin\alpha\sin\beta = \frac{1}{2}[\cos(\alpha-\beta) - \cos(\alpha+\beta)]$ $\cos\alpha\cos\beta = \frac{1}{2}[\cos(\alpha-\beta) + \cos(\alpha+\beta)]$	$\sin\alpha\cos\beta = \frac{1}{2}[\sin(\alpha+\beta) + \sin(\alpha-\beta)]$ $\cos\alpha\sin\beta = \frac{1}{2}[\sin(\alpha+\beta) - \sin(\alpha-\beta)]$
$\sin(2\alpha) = 2\sin\alpha\cos\alpha = \frac{2\tan\alpha}{1+\tan^2\alpha}$ $\cos(2\alpha) = \cos^2\alpha - \sin^2\alpha = 2\cos^2\alpha - 1$ $= 1 - 2\sin^2\alpha = \frac{1-\tan^2\alpha}{1+\tan^2\alpha}$ $\tan(2\alpha) = \frac{2\tan\alpha}{1-\tan^2\alpha}$ $\cot(2\alpha) = \frac{\cot^2\alpha - 1}{2\cot\alpha}$	$sin\left(\frac{\alpha}{2}\right) = \pm\sqrt{\frac{1-\cos\alpha}{2}}$ $cos\left(\frac{\alpha}{2}\right) = \pm\sqrt{\frac{1+\cos\alpha}{2}}$ $\tan\left(\frac{\alpha}{2}\right) = \frac{1-\cos\alpha}{\sin\alpha} = \frac{\sin\alpha}{1+\cos\alpha} = \pm\sqrt{\frac{1-\cos\alpha}{1+\cos\alpha}}$ $\cot\left(\frac{\alpha}{2}\right) = \frac{1+\cos\alpha}{\sin\alpha} = \frac{\sin\alpha}{1-\cos\alpha} = \pm\sqrt{\frac{1+\cos\alpha}{1-\cos\alpha}}$
$\sin^2\alpha + \cos^2\alpha = 1$ $\tan^2\alpha + 1 = \sec^2\alpha$ $1 + \cot^2\alpha = \csc^2\alpha$	$\sin(3\alpha) = 3\sin\alpha - 4\sin^3\alpha$ $\cos(3\alpha) = 4\cos^3\alpha - 3\cos\alpha$ $\tan(3\alpha) = \frac{3\tan\alpha - \tan^3\alpha}{1-3\tan^2\alpha}$
$\sin(4\alpha) = 4\sin\alpha\cos\alpha\,(2\cos^2\alpha - 1)$ $\cos(4\alpha) = 8\cos^4\alpha - 8\cos^2\alpha + 1$	$\sin(5\alpha) = 5\sin\alpha - 20\sin^3\alpha + 16\sin^5\alpha$ $\cos(5\alpha) = 16\cos^5\alpha - 20\cos^3\alpha + 5\cos\alpha$

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