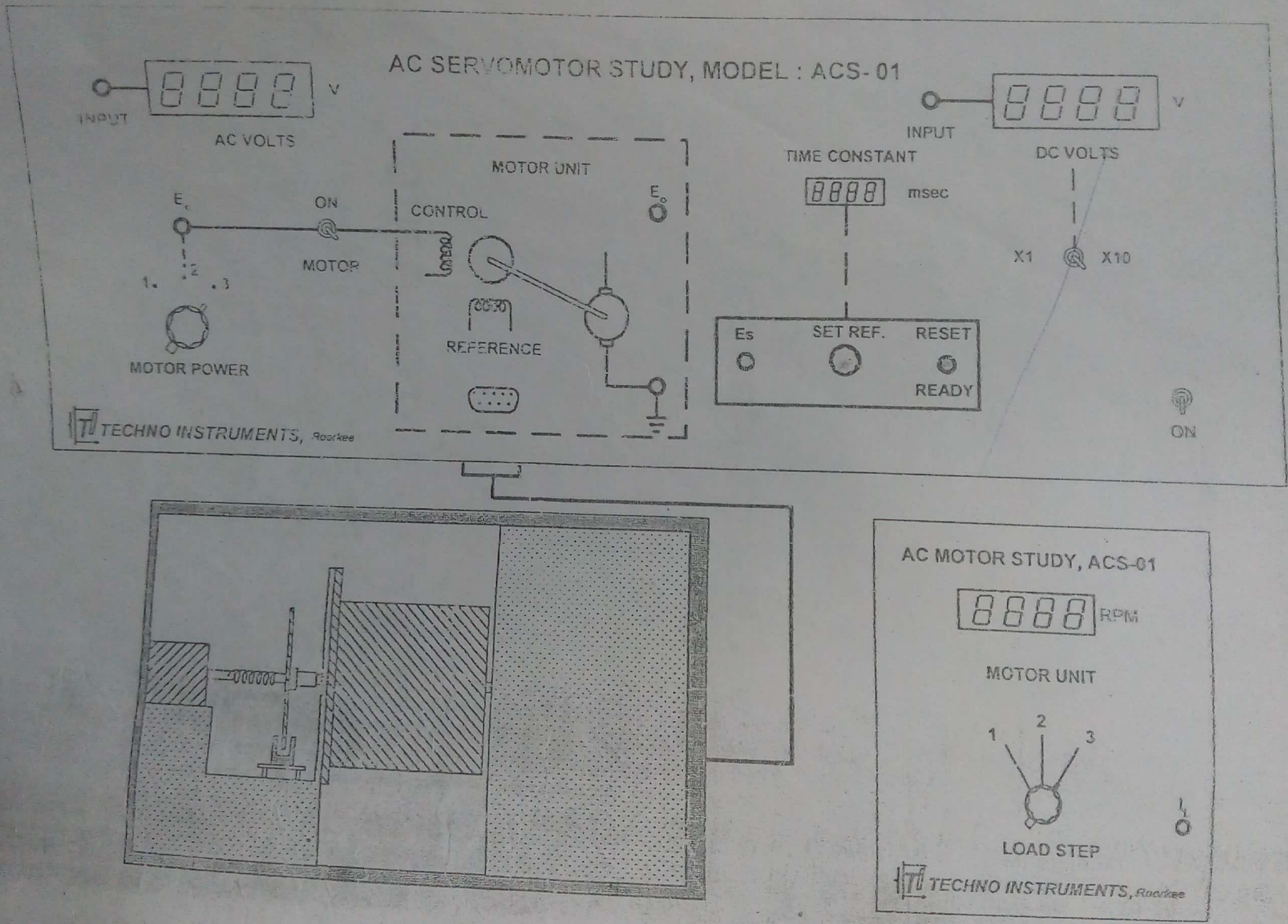


Panel drawing AC Servomotor Study, ACS - 01

STUDY OF AC SERVOMOTOR ACS-01

1. OBJECTIVE

To study the characteristics of a small a.c. servomotor and determine its transfer function.

2. SYSTEM DESCRIPTION

The unit in a self contained system for conducting the experiment except a measuring CRO which should be available in the laboratory. The different components of the unit are explained below.

(a) *AC Servomotor* – a 15W servomotor with identical reference and control phases operating at 12V/ 50Hz. Necessary phase shifting capacitor is pre-wired to the reference phase.

(b) *Electrical load* – in the form of a coupled dc generator and the required resistive load is provided.

(c) *Time Constant* – a special circuit to display the time-constant directly in milli-second.

(d) *Metering* – of all ac and dc voltage/currents is through built-in digital panel meters.

(e) *Power supply* – for conducting all experiments are available in the unit, which operates from a 220V/ 50Hz mains.

3. BACKGROUND SUMMARY

A.C. Servo Motors are basically two-phase, reversible, induction motors modified for servo operation. A schematic diagram of the motor is shown in Fig.1. The two windings, reference and control, may or may not have identical ratings. In the present unit both are rated at 12 volts r.m.s. at 50Hz. A phase shifting capacitor of appropriate value must be connected in series with one of the windings to produce a 90 degree phase shift.

These servo motors are used in applications requiring rapid and accurate response characteristics. A typical torque-speed characteristics of an induction motor is shown in fig.2 for two values of rotor resistance. A servomotor however must have negative slope in its torque-speed characteristics in order to ensure stable operation. To meet the above requirements, these ac servo motors have small diameter, light weight, low inertia and high resistance rotors. The motor's small diameter provides low inertia for fast starts, stops, and reversals. High resistance provides nearly linear torque-speed characteristics. A common structure is a drag-cup rotor. The a.c. servomotors have distinct advantages over d.c. servomotors. The commutator and brush assembly of a d.c. servomotor has limited maintenance free life. These are absent in the a.c.servomotor.

An induction motor designed for servo use is wound with two phases physically at right angles or in space quadrature . A fixed or reference winding is excited by a fixed voltage source, while the control winding is exited by an adjustable or variable control voltage, usually from a servo-amplifier. The servo motor windings are often designed with the same voltage/turns ratio, so that power inputs at maximum fixed phases excitation, and at maximum control phase signal, are in balance. In the present unit the input to the control winding is adjustable (3-steps) and the motor can be switched 'ON' through a switch.

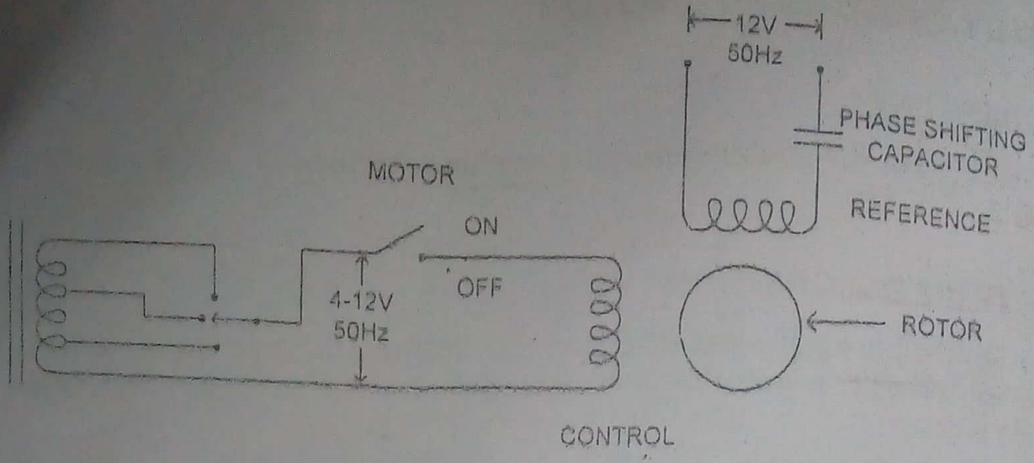


Fig 1 : 2-Phase A.C. Servomotor

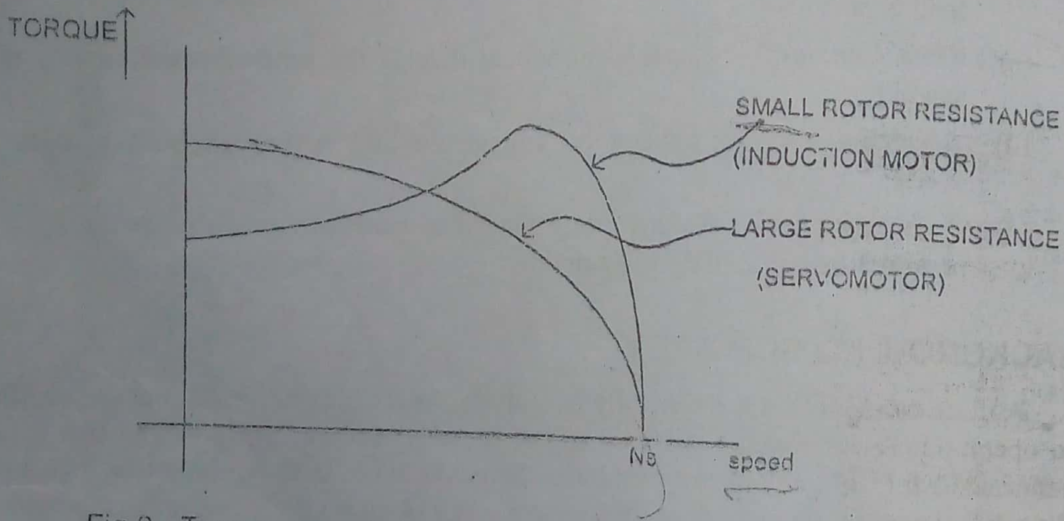


Fig 2 : Torque-speed characteristics of induction motors

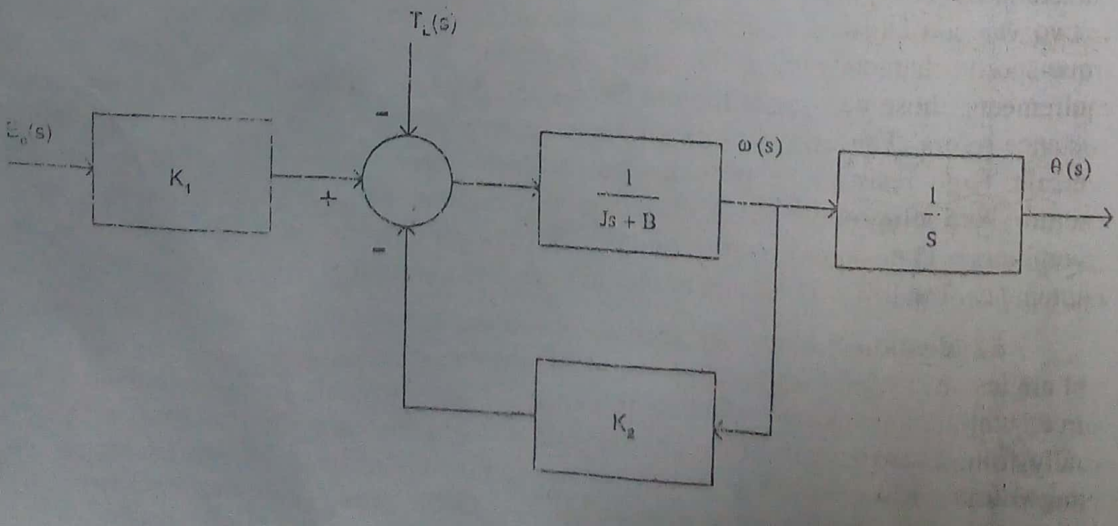


Fig 3 : Block diagram of an a.c.motorsystem

The block diagram of an a.c. servomotor system is presented in Fig.3 This is a highly simplified and linearized version of the actual behaviour of the motor and is valid at low speed of operation only. Detailed description of the working and derivation of the block diagram may be seen in any of the text books listed at the end of this document. Here E_c is the voltage applied at the control phase which results in a proportional torque which however is reduced by a factor related to the motor torque efficiency to generate the actual motor torque as

$T_m(s) = K_1 E_c(s) - K_2 \omega(s)$, where ω is the shaft speed.

This torque, further reduced by the mechanical load torque, T_L, drives the inertia, J and the friction, B of the motor to result in the speed, ω and subsequently the angular position, θ of the motor shaft.

From the block diagram of Fig.3 the transfer function of the motor may be written as

$$\frac{\theta(s)}{E_c(s)} = \frac{K_m}{s(\tau_m s+1)} \quad \text{for } T_L(s) \equiv 0 \qquad (1)$$

where, $K_m = \frac{K_1}{B+K_2}$, and $\tau_m = \frac{J}{B+K_2}$,

are the motor gain constant and the motor time constant respectively. As students of control system, our interest is to evaluate the transfer function and the parameters of the ac servomotor.

Again for $E_c(s) \equiv 0$,

$$\frac{\theta(s)}{T_L(s)} = -\frac{\frac{1}{B+K_2}}{s(\tau_m s+1)} = -\frac{K_n}{\tau_m s+1}, \text{ where } K_n = \frac{1}{B+K_2}$$

Combining the above two transfer functions (under assumption of linearity),

$$s\theta(s) = \omega(s) = \frac{K_m}{(\tau_m s+1)} E_c(s) - \frac{K_n}{(\tau_m s+1)} T_L(s)$$

The computation of K_m and K_n can be done by using the final value theorem, i.e.,

$$\text{Steady state speed, } \omega_{ss} = \lim_{s \to 0} s\omega(s) = K_m E_c - K_n T_L \qquad (2)$$

where

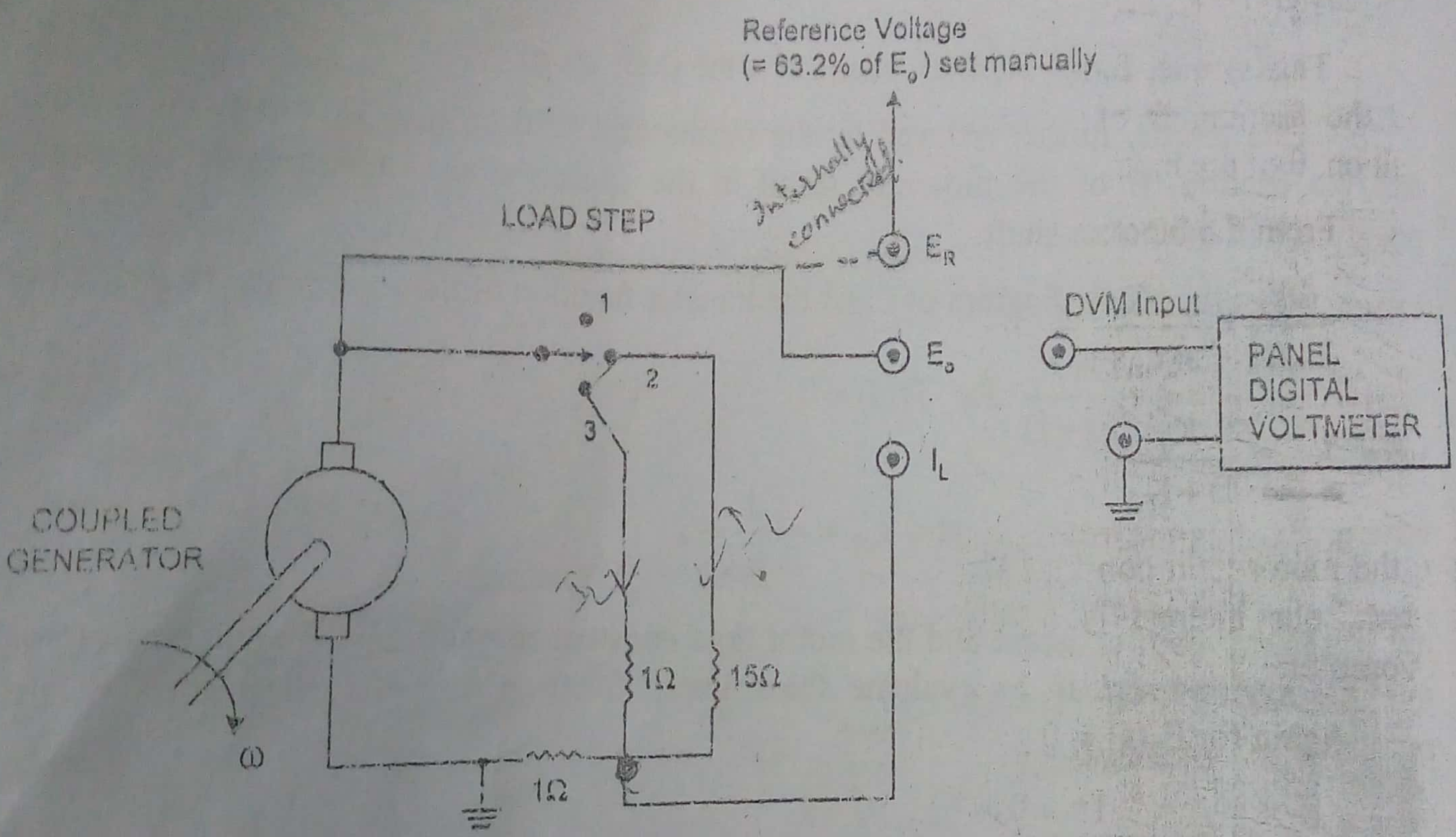
E_c = Constant voltage applied to the control winding

T_L = Constant Load torque

E_c Is measured by the a.c. voltmeter on the panel and T_L is calculated from the loading of the coupled d.c. generator as ,

$$T_L = \frac{\text{Electrical Power drawn from the generator in watts}}{\text{Angular velocity of the shaft in radians/sec}}$$

The calculation assumes that the generator mechanical parameters are negligible compared to that of the servomotor.



DVM input to be externally connected to terminal
E_o To measure generator output voltage
E_R To measure 63.2% of E_o for Time-constant measurement
I_L To measure load current as the drop across 1Ω resistance

Fig : 4 Loading circuit arrangement

All the above results are strictly valid if the system is perfectly linear. This is true to a great extent, especially at low speeds, and will form the basis of conducting the present experiment. Another option, though cumbersome, is to determine experimentally the torque-speed and torque-control phase voltage characteristics and then to linearize these graphically to evaluate the motor parameters, K_1 and K_2, and then to calculate K_m, τ_m, J and B.

4. EXPERIMENTAL WORK

The a.c. motor study is divided into groups (a) steady state – to determine K_m and K_G, and (b) transient – to determine τ_m. From these the transfer function and other constants are calculated.

4.1 Steady State Operation

4.1.1 Determination of Generator Constant

The generator constant, K_G, in volts/rpm, may be computed from the no load generator voltage data at various speeds. This would enable one to calculate the generated voltage under loaded condition, which is needed for torque computation in the next section. The readings for the present experiment may be tabulated as below:

TABLE – 1

INPUT STEP	MOTOR SPEED, N_r, RPM	LOAD STEP-1 (No Load) Voltage, Volts	GENERATOR CONSTANT, K_G, Volts/rpm
1.	1255 rpm	2.63 volt	0.00209 Volts/rpm
2.	1869 rpm	3.84 volt	0.00205 Volts/rpm
3.	1928 rpm	3.99 volt	0.00207 Volts/rpm

Average Generator Constant, $K_G = 2.07 \times 10^{-3}$ Volts/rpm

4.1.2 Determination of Motor Parameters

The motor is operated at various combination of control phase voltage E_c and external loading, T_L, and the data is recorded as in Table-2. E_c is measured with the help of the a.c. voltmeter on the panel in three steps while no load generator voltage, E_g and load currents, I_L are measured by a switchable d.c. panel meter provided. The loading circuit is shown in Fig. 4

Operating at no load (load step-1), ie., $T_L = 0$, using equation (2) the motor gain constant may be calculated as

$$K_M = \frac{\omega_{ss}}{E_C} = \frac{N\pi}{30E_C}$$

An average value for K_m may be obtained from the three input voltage steps provided.

K_{m1}=54.31 rad/ volt-sec

K_{m2}=27.53 rad/ volt-sec

K_{m3}=18.77 rad/ volt-sec

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TABLE – 2

INPUT		LOAD STEP –1 (no load)				LOAD STEP -2			LOAD STEP-3		
STEP	E_c, rms V	E_0, Volts	I_L, amp	N, rpm	$T_L = (30 . E_0 . I_L / N . \pi)$	I_L	N	$T_L = \frac{(30 K_G I_L)}{\pi}$	I_L	N	T_L
1.	3.80	2.66	0	~~[illegible]~~	0	0.05	667	0.0016	0.067	470	0.0013
2	[illegible]	[illegible]		1211	0	[illegible]	1273		1.43	296	
3	10.90	4.52	10	1986	0	1.17	1529		1.84	1170	

$E_s = 0.633 E_c$

10

Deth 50%

$k_p \sim 2e$

$K_v \simeq 0.036$

$V_{av} = 2.35$

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33.53

$$K_m = \frac{K_{m1} + K_{m2} + K_{m3}}{3} = 33.53 \text{ rad/volt} - \text{sec}$$

An average value for K_m may be obtained from the three input voltage steps provided although the three values of K_m obtained are very different from each other due to the motor non-linearity.

Similarly, operating at a constant E_c and two different load steps, one gets

$$\omega_{ss1} = K_m E_c - K_n T_{L1}$$

$$\omega_{ss2} = K_m E_c - K_n T_{L2}$$

From these, K_n may be obtained as,

$$K_n = \frac{\omega_{ss1} - \omega_{ss2}}{T_{L2} - T_{L1}}$$

or, the effective friction as

$$B + K_2 = \frac{T_{L2} - T_{L1}}{\omega_{ss1} - \omega_{ss2}}$$

The inertia, J, may further be calculated from

$J = \tau_m . (B+K_2)$, after τ_m is computed as outlined in sec, 4.2

4.2 Transient Operation

The time constant, τ_m is the time taken by the motor to reach 63.2% of the steady state speed when a step voltage is switched on the control winding while the reference winding is already excited at the rated voltage. In the present unit this is achieved through a special circuit which displays the time constant in milli-seconds. The steps for operating this circuit are given below:-

Step. 1. Switch the motor 'ON' at input step.3 (rated voltage). A constant speed will be indicated almost immediately.

Step .2. Read V_0 at Load step-1. Set 'REFERENCE' potentiometer in the TIME CONSTANT SECTION to 63.2% of the E_0 value read above. Use the d.c. voltmeter in the SET REF position.

Push RESET switch to READY

Step. 3. Switch the motor 'OFF', wait for 30 seconds and then switch it to 'ON' position. The time constant will be displayed in msec.

The time constant obtained above may have error due to non-linear friction present. It is therefore desirable to conduct the experiment a number of times and average the result.

5. RESULTS AND DISCUSSIONS

The results given below taken from a sample unit for input-3 and may differ from the unit supplied to you. This is because of the variation in the characteristics of the motor generator and to some extent on the experimental errors.

(a) Reference winding input, E_c = 12.0 V, rms

Motor speed, N = 1928 rpm

Generator coefficient, K_G = 2.07×10^{-3} volts/ rpm

(b) Reference winding input, $E_c = 12.0$ V, rms

Motor speed, N $= 1972$ rpm

Motor gain constant,

$$K_m = \frac{N\pi}{30E_c} \text{ rad/v-sec} = 18.77 \text{ rad/v-sec}$$

(c) Reference winding input, $E_c = 12.0$ V, rms

Motor time constant, $\tau_m = 110$ msec 16

(d) Transfer Function of the motor

$$G(s) = \frac{K_m}{s(s\tau_m + 1)} = \frac{18.77}{s(0.11s + 1)}$$

The typical results shown above are all based on averaged set of data. These are primarily aimed at showing the method. The students are expected to complete the experiment in detail.

Further, the above experiment computes the motor transfer function only, which is probably the most significant result. In addition to this, the students may compute inertia J and effective friction ($B + K_2$) as well, as outlined in section 4.12

The most important assumption in this experiment is that of considering the system to be linear. Strictly speaking the a.c.servomotor and the d.c. generator are both non-linear. Further, there are non-linear friction components which have been totally neglected. All these contribute to errors in the result although the transfer function derived represents the actual behaviour of the motor pretty well, at least at low speeds

6. REFERENCE

[1] M. Gopal, "Control Systems – Principle and Design", Second Edition, Tata McGraw Hill Publishing Co. Ltd., pp.168-174.

2.85

1.27

4.50

1972

$\tau_M = 135$ msec