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MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

JET ENGINE STARTING WITH VARIABLE TIME BASE

BY

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ABSTRACT

Nowadays, jet engine starting systems on majority of aircrafts are working with constant time base, the fact that ignores the conditions of the started engine and feeding sources. We mean by constant time base starting of engine that a certain time mechanism, which operates independently, controls the process of starting cycle intervals. It means that at certain prescribed intervals of times, this mechanism pushes the starter motor to operate, then raises its speed, then lets aggregates (fuel pumps, ignition system,...) to take part in the process, ... and so on. Starting by this way is unsuitable from points of view of engine efficiency, reliability, and even the longer starting time. The using of solid state starting devices, allows to make a variable time base according to real parameters of started jet engine, and so to optimise the whole starting process. Main parameters of engine are its speed and temperature of gases in front of turbine plades (T3*). This work deals with convential starting panels with constant time base, their advantages and disadvantages, and gives a praliminary solid state circuit that fulfills the variable time base starting process of an aircraft jet engine.

The later configuration is very convenient from points of view of efficiency, reliability, weight and size, radio interference, and starting period. Besides, such concept may be found suitable with respect to starter motor efficiency. The designed circuit was applied practically to starter motor CT-2-48B in laboratory, and proved its applicability for such use. This circuit was designed to be suitable for use on ground and also during flight.

INTRODUCTION

The main task of the starting device of the aircraft engine is to set the engine rotor spining from speed n=0 to a stable (idle run) speed. Fig.(1) shows the compressor resistive torque N_C and the driving turbine torque N_T versus engine speed n.

In this figure, it is clear that the idle run speed is reached at the moment of equilibrium of N_C and N_T. Practically, the characteristic $N_T=N_T(n)$ can be approximated by a system of parallel straight lines (at $N_T=0$, corresponds to the speed at which fuel ignition occurs) depending on the actual temperature T3*.

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The locus of equilibrium points $T_3^* = T_3^*(n)$ is shown in upper part of fig.(1).

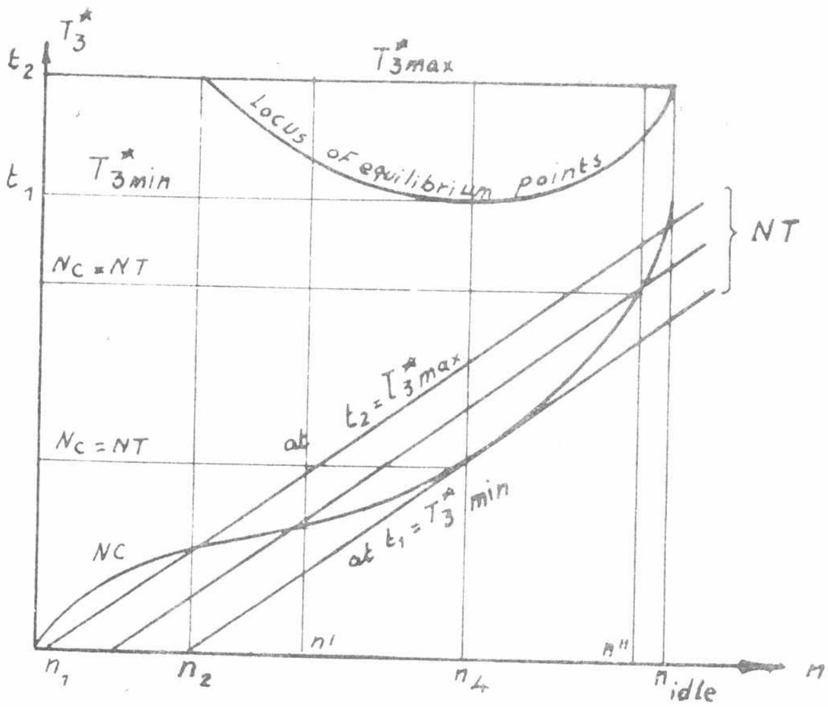

Fig.1

Generally equilibrium occurs at two points for each straight line (i.e.n' and n"). No equilibrium occurs within the range n_2 to n=0. Equilibrium occurs between n_2 and n_4 only by decreasing T_3^* to T_3^* min. The steady state equilibrium never happens for $T_3^* < T_3^*$ min=t_1.After n_4 equilibrium occurs by increasing T_3^*. At $n=n_{max}$(idle run speed) equilibrium occurs for $T_3^* = T_3^*{}_{max} = t_2$. The value of T_3^* max depends on the constructional parameters of engine. The warming up period to reach idle run (starting time t_s) must be as short as possible. On the other hand, the idle run speed is selected in such a way that engine can rotate with this speed without any time limitation. Sufficient excess power for required acceleration must be guaranteed at n_{idle}. Application of external torque to engine shaft is necessary. Starter motor with torque speed characteristic $M_{st} = M_{st}(n)$ as shown in Fig.(2)b, should be employed. The programmed fuel delivery $G_f = G_f(n)$ has the shape as illustrated in fig.(2)a, (in order to achieve the required turbine characteristic shown in fig.(2)b.

CONSTANT TIME BASE STARTING PROCESS CTBS

Fig.(3) shows a starting panel with constant time base. It consists of three main parts: a timer, two power contactors, and a series resistance R_s. The timer consists of an electromotor with shaft controlling four cams. Since timer motor speed is assumed to be constant, each cam will close a micro switch after specified interval of time. For example, cam N_1 close the circuit of self supply of whole circuit (no need to keep starting push button P.B). After certain time, cam N_2 puts the starter motor M into operation (through contactor KM 200 DI) with series armature resistance R_s. Also cam N_2 puts all aggregates into operation. After certain time, cam N_3 achieves the short circuiting of R_s (through contactor kM 200 D2).Hence, starter

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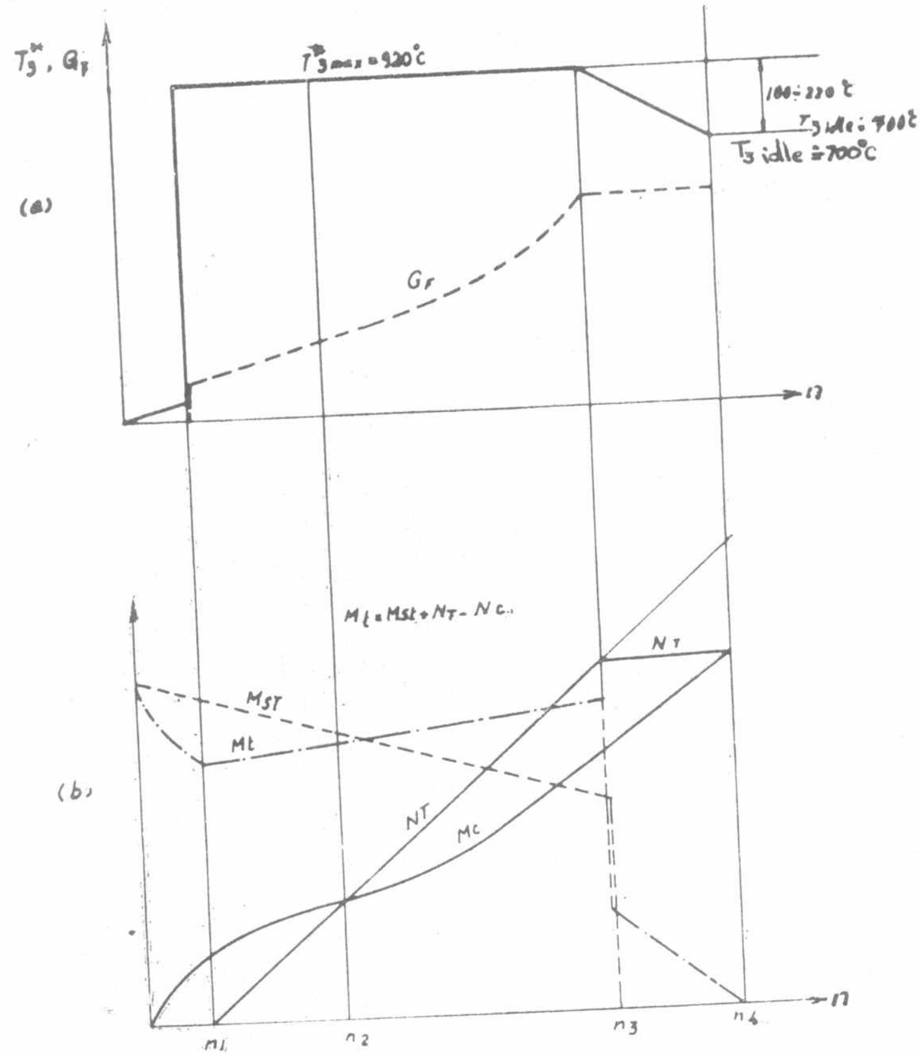

Fig.2

speed rises. Cam N_4 connects the + terminal to the shunting contactor.

VARTABLE TIME BASE STARTING PROCESS VTBS

In the variable time base starting process, individual tasks achieved in CTBS at specified times, will be achieved depending on engine real condi ions (T_3* and n). Fig.(4) shows the block scheme of the suggested circuit to fulfill the VTBS. The Schmitt circuits were designed to respond at different levels corresponding to different values of n and T_3*. Such levels will be dependent on sensing elements of T_3* and n. In this circuit the Schmitt circuit for n_1 was made to respond at input voltage V_{in}=IV, for n_2 V_{in}.=1,4 V, for n_3 V_{in}=3,4 V for t_1: V_{in}=1,9V, and for t_2:V_{in}=3,4V. Combinations of outputs of individual Schmitt circuits are fulfilled through a NOR gate (realized by ECL circuit). Fig.(5) shows all possible combinations between n_2,n_3,t_1,and t_2. The symbol Y indicates the output of OR gate (BCL). Symbol M indicates the operation of the starter motor (NOR gate of ECL). Speeds n_1,n_2,n_3 are shown in Fig.(2)b. n_1: Speed at which engine is inginted and turbine starts to produce torque.

n_2: Equilibrium N_c=N_T for T_3*=T_3* max.

n_3: Speed at which starter motor should be separated.

t_1= T_3* min.

t_2= T_3* max.

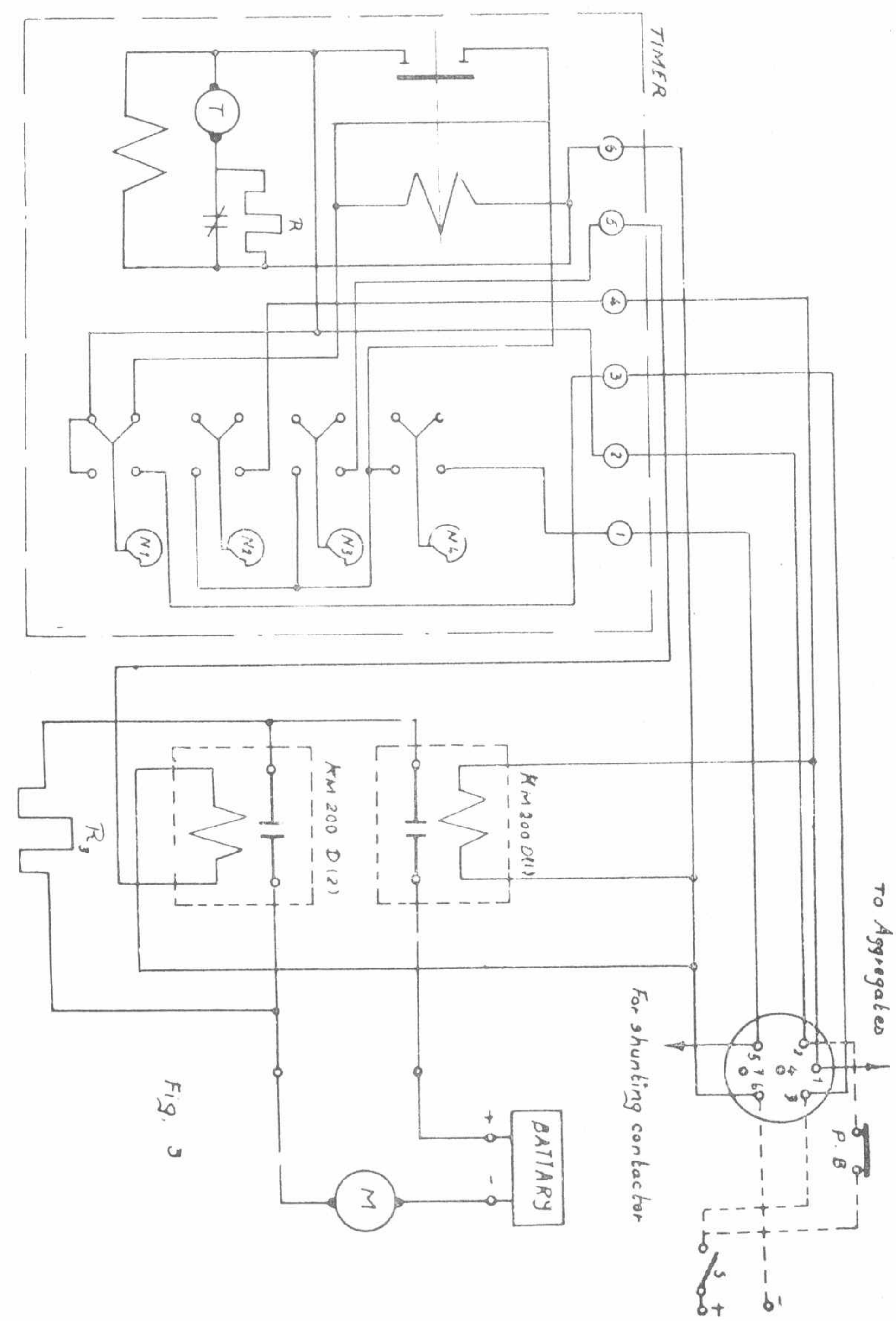
TIMER
T
R
KM 200 D(2)
KM 200 D(1)
BATTARY
M
To Aggregates
For shunting contactor
P.B
Fig. 3

Fig.3.

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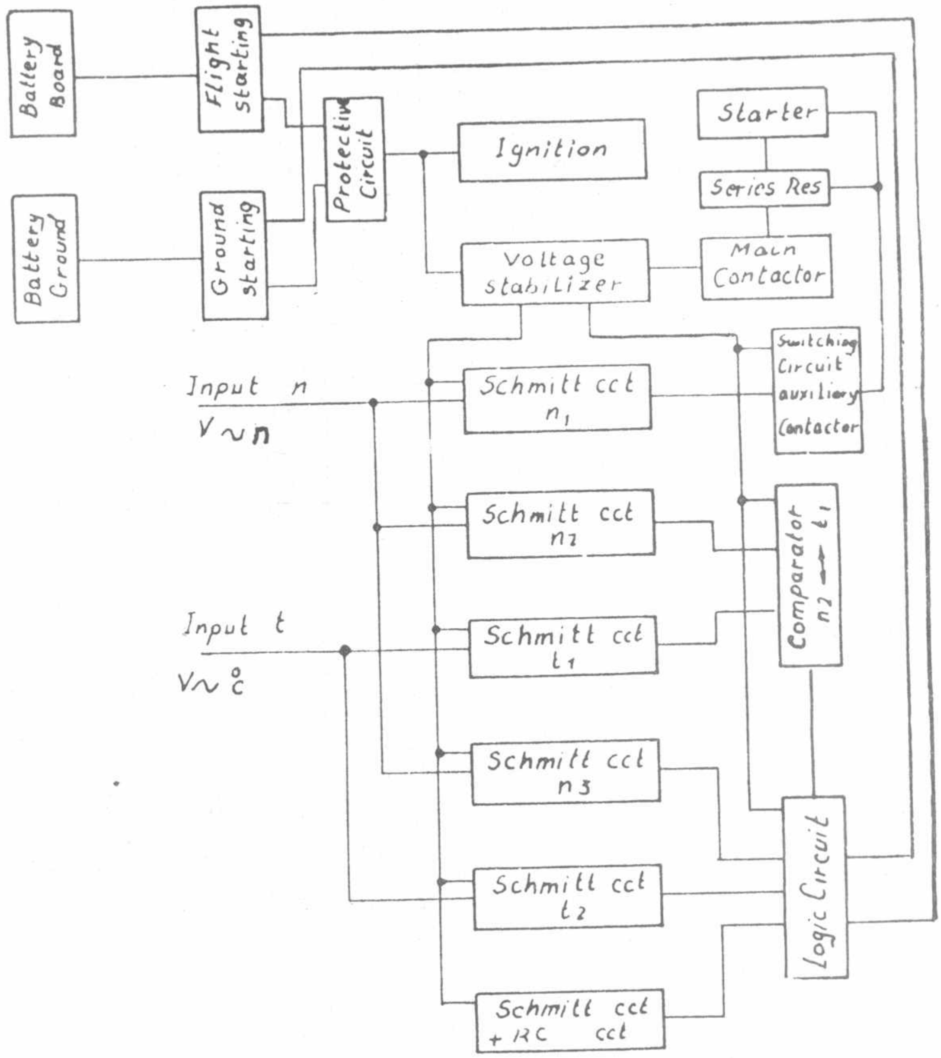
Battery Board
Flight Starting
Battery Ground
Ground starting
Protective Circuit
Ignition
Starter
Series Res
Main Contactor
Voltage stabilizer
Input n
V ~ n
Input t
V ~ °C
Schmitt cct n1
Schmitt cct n2
Schmitt cct t1
Schmitt cct n3
Schmitt cct t2
Schmitt cct + RC cct
Switching Circuit auxiliary Contactor
Comparator n2 → t1
Logic Circuit

Fig.4.

n_2	n_3	t_1	t_2	$n_2\bar{t}_1$	Y	M	Remarks
0	0	0	0	0	0	1	
1	0	0	0	1	1	0	
0	1	0	0	0	1	0	Can not occur
1	1	0	0	1	1	0	
0	0	1	0	0	0	1	
1	0	1	0	0	0	1	
0	1	1	0	0	1	0	Can not occur
1	1	1	0	0	1	0	
0	0	0	1	0	1	0	can not occur
1	0	0	1	1	1	0	" " "
0	1	0	1	0	1	0	" "
1	1	0	1	1	1	0	" " "
0	0	1	1	0	1	0	" " "
1	0	1	1	0	1	0	" " "
0	1	1	1	0	1	0	can not occur
1	1	1	1	0	1	0	" " "

Fig.(5)

From table it is clear that:

- When motor speed reaches n_2 while $T_3^* < T^*_{3min} = t_1$, M stops operation.
- At n_3 starter motor should stop its operation.
- At $T_3^* = T_3^*{}_{max} = t_2$, M should stop its operation.

  Otherwise, the starting cycle will continue.

  Besides, there are some combinations which can never happen.

Therefore,

$$M = \bar{n}_2\bar{n}_3\,\bar{t}_1\bar{t}_2 + n_2\bar{n}_3 t_1\bar{t}_2 + \bar{n}_2\bar{n}_3 t_1\bar{t}_2$$

$$= \bar{n}_2\bar{n}_3\bar{t}_2 + \bar{n}_3 t_1\bar{t}_2 = \bar{n}_3 t_2(\bar{n}_2 + t_1)$$

Fig.(6) shows the complete circuit diagram fulfilling the task of starting process control. It is a solid state circuit,corresponds to block scheme in fig.(4) with variable time base. In addition, it solves the problem of starting on ground, as well as during flight.

ENGINE VTBS ON GROUND

On ground, we may have either normal, or cold, or dummy engine rotation. Procedure of normal starting is as follows:
We press the push button type LUN 3211 determined for starting on ground. Therefore, contacts (1,2),(3,4) will be closed.Hence, positive voltage (+) appears at contacts (3,4),(5,6) and also at terminals 1 and 2 of socket A. Then, voltage stabilizer (feeding all schmitt circuits and ECL by stabilized voltage 12V),will be supplied by input 28V. Simultineausly, + voltage is supplied to igniter. Negative terminal will be common for all circuits through point 4 of the socket. Contactor KM 200 D1 will be now energized, leading to the operation of starter motor M. Since speed does not reach n_2, n_3, and temperature does not reach yet t_1, Schmitt output voltages corresponding to these parameters are all zeros, hence output of ECL is zero too. Therefore, the Y_r winding will be energyzed since its lower terminal is earthed. Then contacts of LUN 3211 will be closed regardless to whether push button is kept pressed by hand or not. When engine rotation reaches n_1, contactor KM 200 D2 will be energized, and series starting resistance R_s will be short circuited, hence M speeds up. Circuit responded to n_1 consists of two Schmitt circuits for purpose of inversion and wave shaping. For any of the three cases at which starter motor should stop its operation, the output of ECL will be logical one, and widning Y_r will be deenergized. Contacts of Y_r will come to initial positions ((7,8),(9,10),(11,12) are closed disconnecting power supply from contactors KM 200 D1 , and KM200D2. Hence, starter M stops operation. /

ENGINE VTBS DURING FLIGHT

With the engine started in the air, the starter motor does not participate in spining up the engine rotor, the engine in this case being spun up by autorotation. In order to start the engine during flight we proceed as follows. Push button LUN 3211 determined for starting during flight is pressed, where contacts (1,2),(3,4), and (5,6) are closed. Then terminals 1 and 2 of socket is connected to voltage 28V. Negative terminal will be applied to point 4 of socket to common earth of circuit. Ignitor will be ON. Stabilizer is now energized to give 12V output . Due to the fact that engine speed is less than n_2 and its temperature is less than t_1, output of ECL will be OV, hence winding X_r is energized keeping the closing of contacts (1,2), (3,4), and (5,6). Ignition coils will be off as the winding X_r is de-energized. Winding X_r is de-energized for same conditions described in case of starting on ground.

CONCLUSION

In the CTBS process, the intervals of times determined by timing mechanism are specified considering engine characteristics does not change. Practically, it may happen due to some mistake in aircraft engine, that its temperature rises beyond the permitted value. Also, due to wearing or unbalanced location of ball bearing, the breaking moment increases, and engine will not rotate in desirable manner. Besides the compressor characteristic is a function ofthe surrounding conditions which are always changing. Also friction torque and moment of aggregates will be changed due to wearing or unbalanced location of ball bearing .
In the VTBS, the intervals of starting cycle will be dependent on both gas temperature, and engine speed. Such arrangement is very advantageous from points of view of reliablity, efficiency, service life, weight and size,

radio interference, and starting time.
In labroatory the circuit of Fig.6, was realized and applied successfully for starting process of starter motor ,CT-2-48B. Both signals refereing to speed n and temperatur T_3* of engine were supplied by an external low voltage source. Further development of such circuit are:

1- Replacement of power contactors by solid state contactless relays.
2- Replacement of starting resistance by solid state contactless element.

Fig.(7) shows the realized solid state circuit beside the convential starting (CTBS) panel. Fig.(8) shows the connection of this new starting panel to drive the starter motor CT-2-48B into operation.

REFERENCES

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2- L.D.Dickey, "Solid state switching for an aircraft electric system". IEEE Spectrum, Nov. 1970.
3- F.L.Hamilton,"Application of transistor technique to relays and protection for power systems".
Proceeding of IEE, Vol. 114, Feb. 1967.

fig.(7)

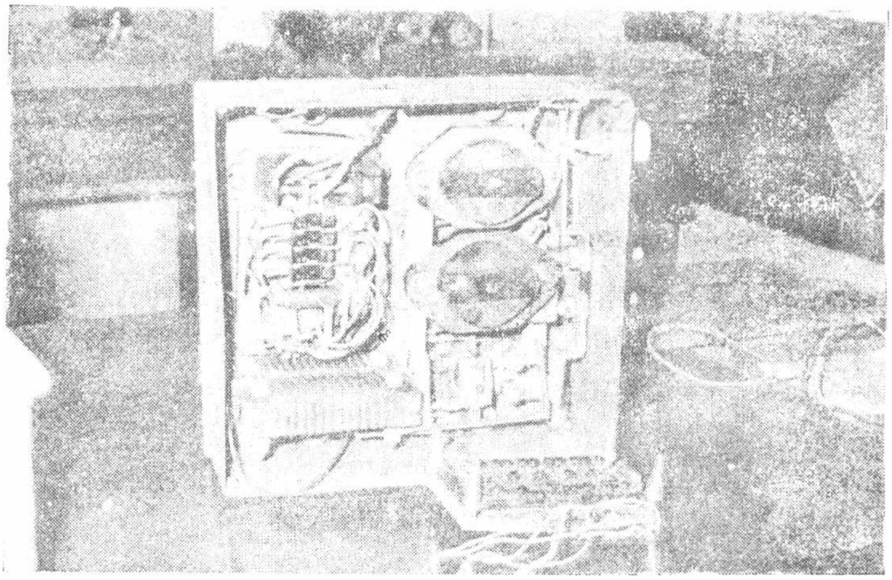
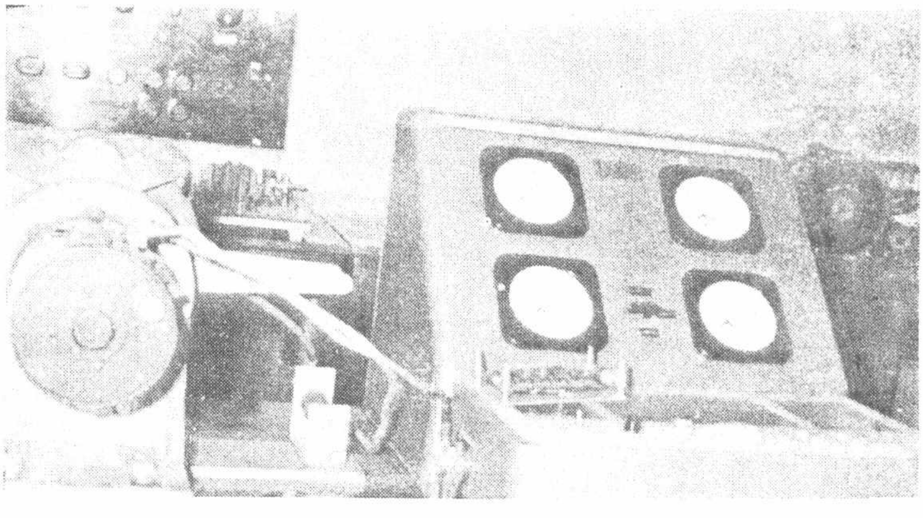


fig.(8)



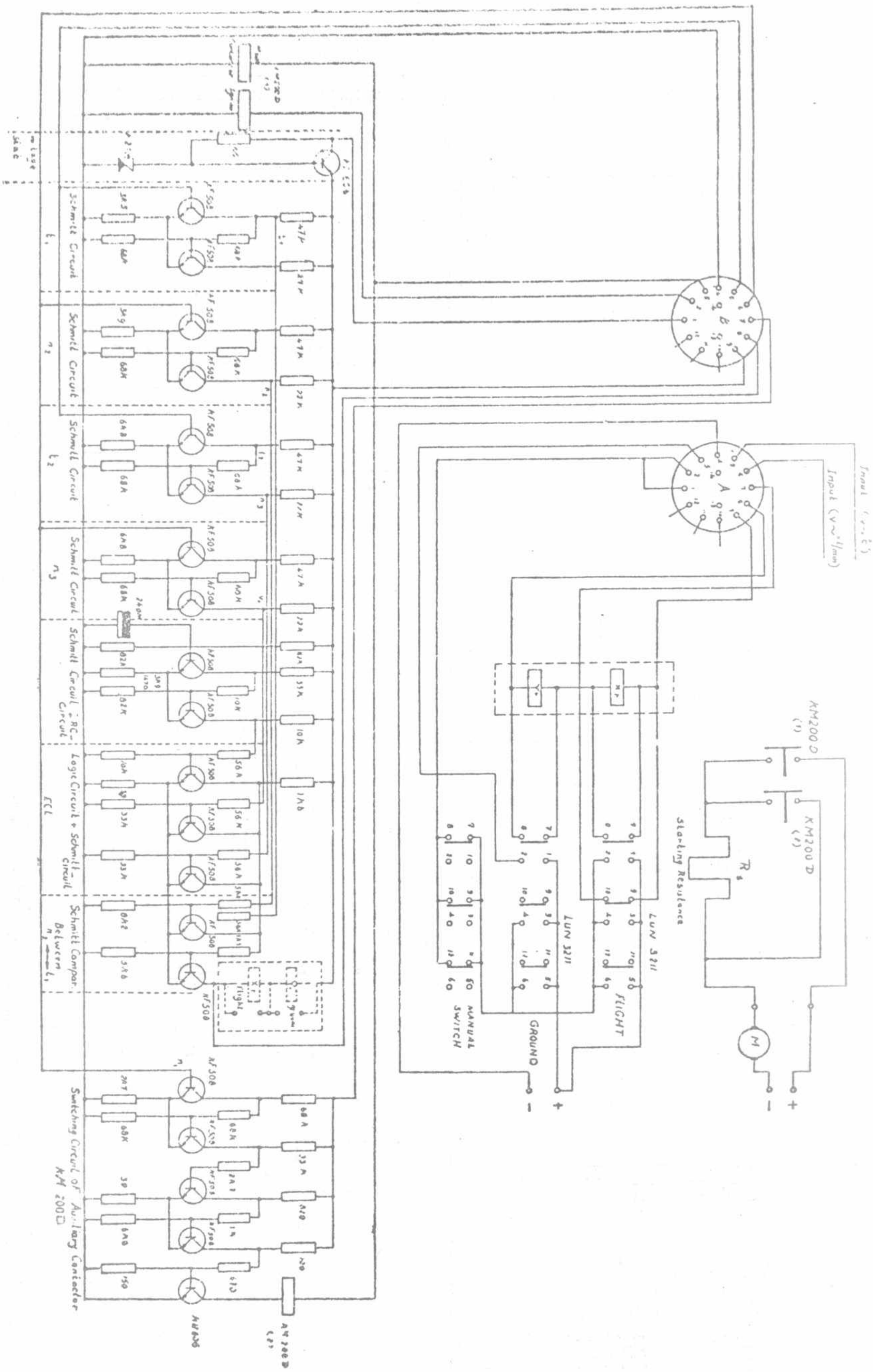

Schmitt Circuit
Schmitt Circuit + RC-Circuit
Logic Circuit + Schmitt Circuit
ECL
Switching Circuit of Auxiliary Contactor KM 200D
AF508
MANUAL SWITCH
GROUND
FLIGHT
LUN 3211
Starting Resistance
KM200D
M

fig.6

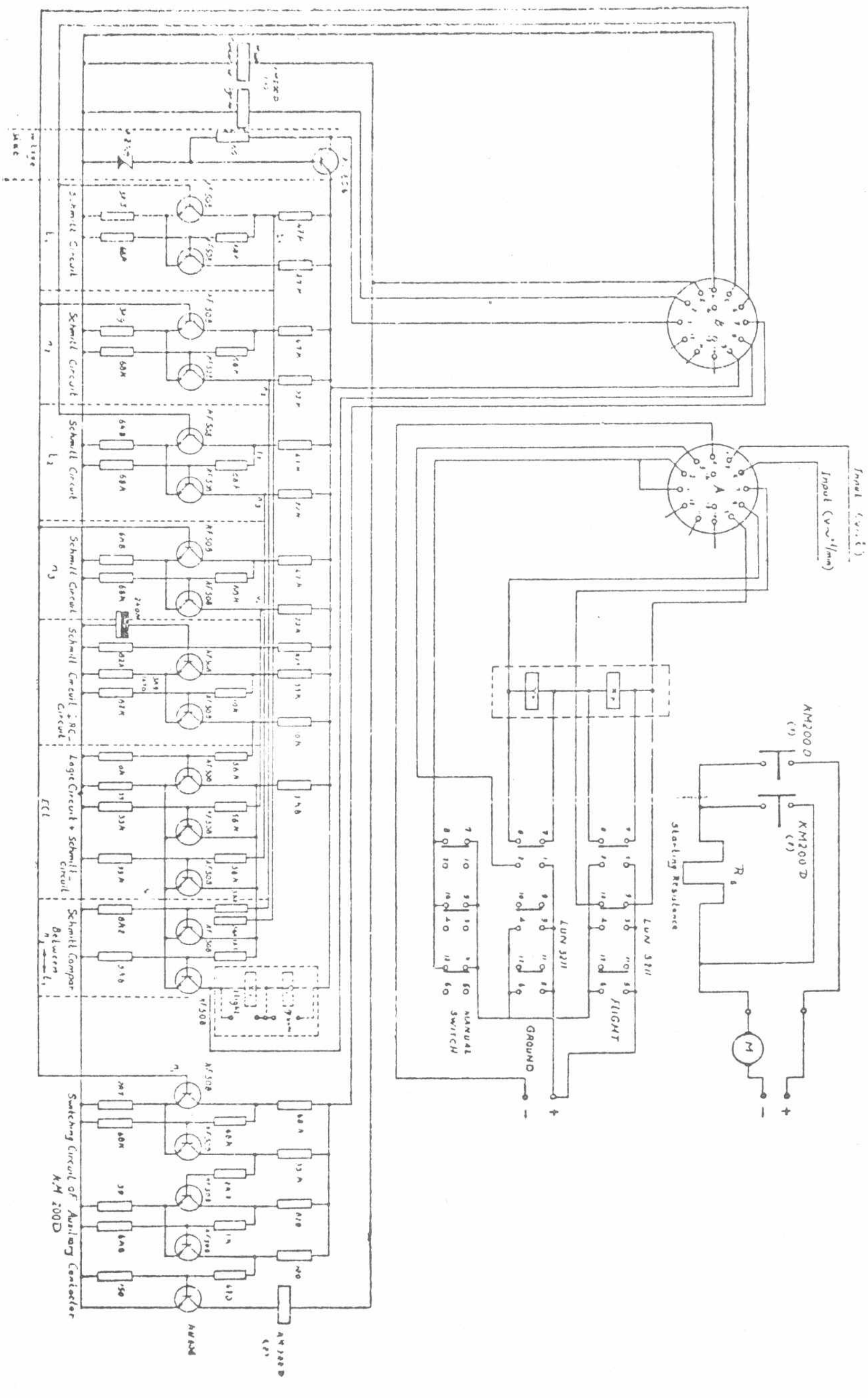

Schmitt Circuit
Switching Circuit of Auxiliary Contactor K.M 200D
MANUAL SWITCH
GROUND
FLIGHT
LUN 3211
KM200D
Starting Resistance

fig. 6

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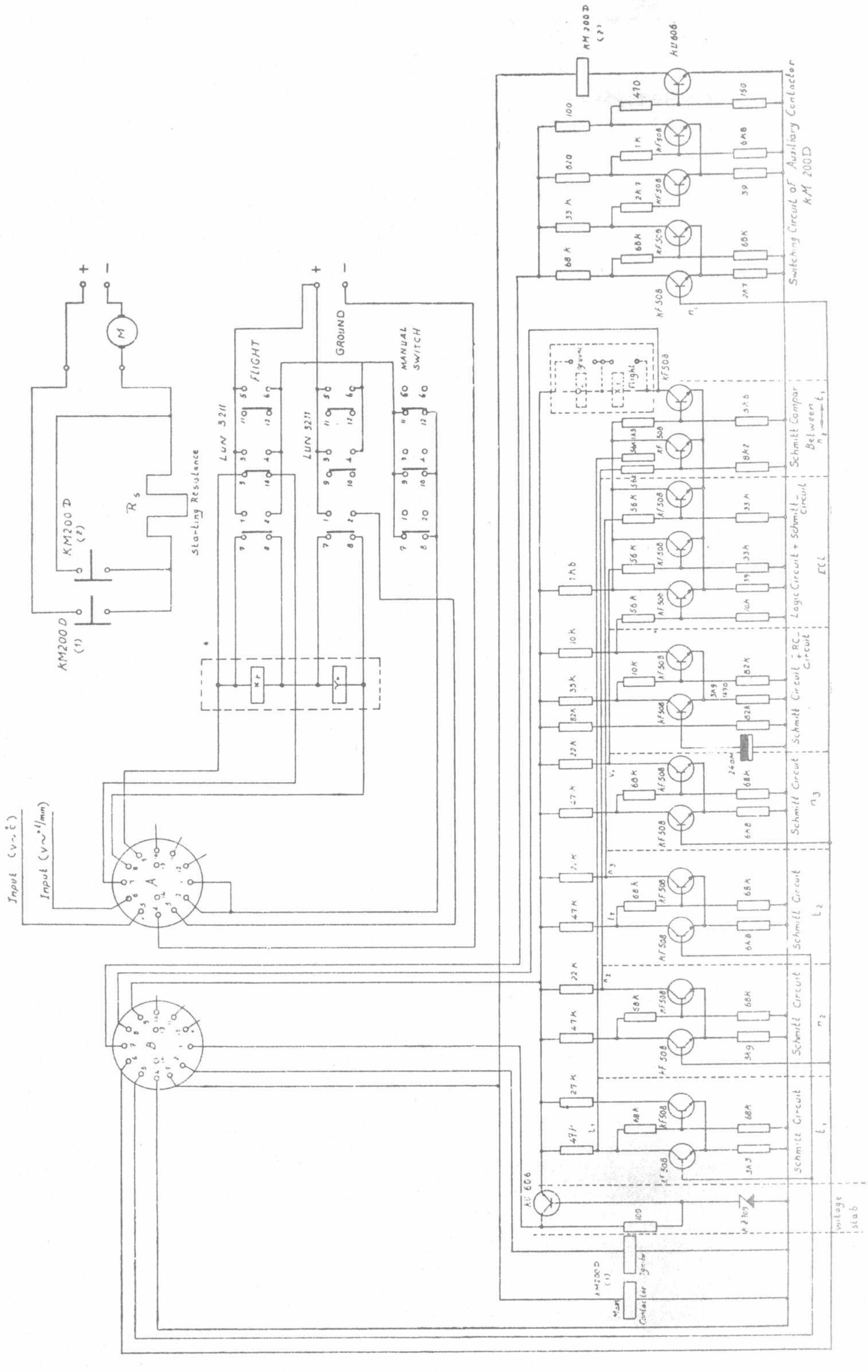

Fig. 6