1977

Preliminary Report: Umass Wind Turbine Operation

None Listed

Preliminary Report

UMass Wind Turbine

Operation

December 1977

Ref. UM-WF-PR-77-3

c. Preliminary Performance Report WF-1

The following constitutes a preliminary report of the UMass Wind Turbine, WF-1.

1.1 Review of the Operating Regions for the Wind Furnace and the Controllers: (Ref. Figure 1.1).

1. Region 1: Start-Up

The blade pitch is set at the start-up angle until the shaft speed reaches the cut-in speed (A) for the pitch controller. At this point the pitch controller pitches the blades to the operating pitch angle for region 2. If the Rpm drops below this cut-in RPM the blades will return to the start-up pitch angle.

2. Region 2: Constant Pitch Angle

The pitch angle remains constant between the cut-in shaft speed (A) and the rated shaft speed (B). When the shaft speed reaches 37 Rpm the field controller excites the generator field. This excitation level, denoted by the field current, varies with Rpm. At rated Rpm and above, the field excitation will remain at a constant value. The purpose of varying the excitation is to maximize the power output without stalling the blades.

3. Region 3: Constant Shaft Speed

Once the shaft speed reaches the rated value and begins to increase further, the pitch controller will increase the blade pitch angle to try to maintain the rated Rpm. If rate Rpm is maintained the power level can be held to 25 kw regardless of the wind speed.

4. Region 4: Shut Down Due to High Winds

If the wind speed exceeds a maximum value the pitch controller will feather the blades.

5. Operation of the Pitch and Field Controllers:

An objective of the design for this WTG was to allow for complete automatic operation of the WTG via two controllers: the blade pitch controller and the field excitation controller.

The blade pitch controller has been designed to fulfill certain criteria and yet be flexible enough so that changes can be made without extensive re-working of the controller. The criteria consisted of four different types of pitch control, as exemplified by the four operating regions. The flexibility was derived by allowing wide adjustments in pitch angle and in transition Rpm (A,B) for these regions to be made simply and quickly.

The primary signal for the pitch controller is shaft speed. All decisions as to pitch angle are made according to the instantaneous shaft Rpm. Adjustments in pitch angle and transition Rpm are made by varying the reference voltage input to voltage comparators in that part of the circuitry which controls the region of interest.

The field controller was also designed as a standard circuit unit with built-in flexibility. This controller uses a programmed memory to lock the desired field current for a particular Rpm range (Fig. 1.2). By varying the supply voltage, limited adjustments in field current can be made. For more extensive changes complete reprogramming is required.

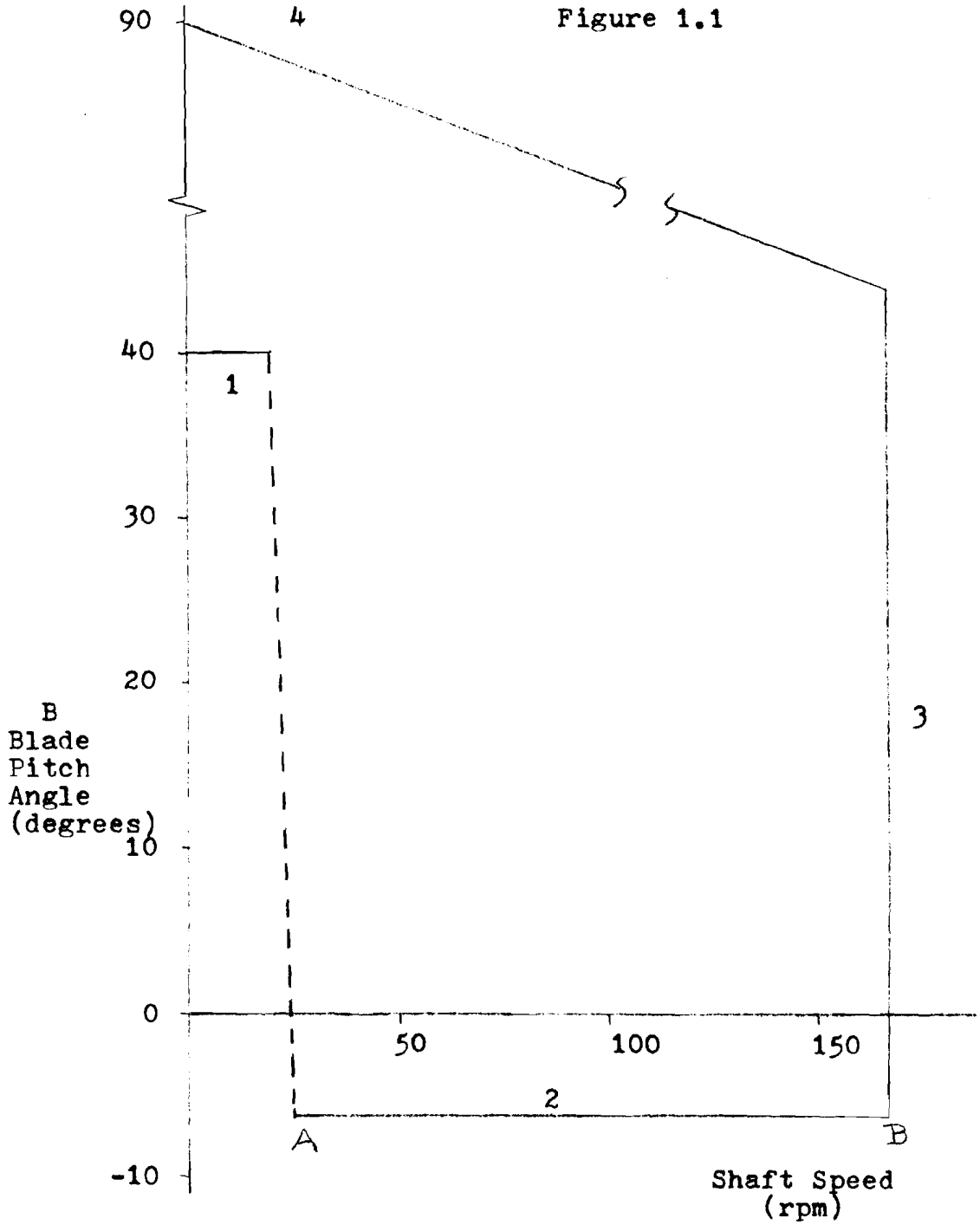

90
40
30
20
10
0
-10
B
Blade
Pitch
Angle
(degrees)
1
2
3
4
A
B
50
100
150
Shaft Speed
(rpm)

Figure 1.1

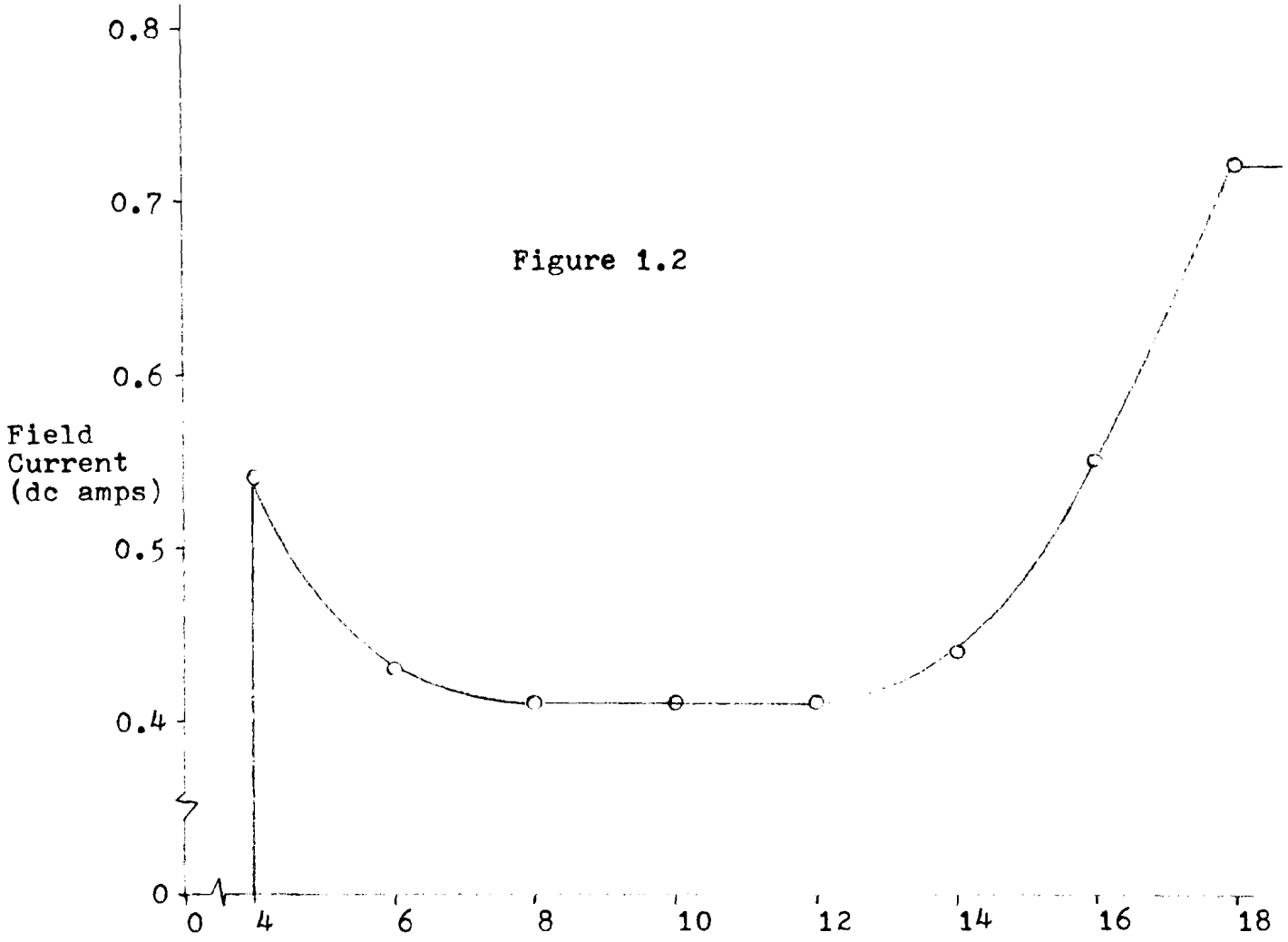

0.8
0.7
0.6
Field
Current
(dc amps)
0.5
0.4
0
0
4
6
8
10
12
14
16
18
Generator Shaft Speed (hundreds of rpm)

Figure 1.2

1.2 Actual Operation of the Wind Furnace

1. For the months of September, October and most of November the winds have been less than expected. The actual data to verify this remark is still being processed. Because of this, a minimum number of tests have been carried out and these have been run in the month of November.

   Another consideration in scheduling tests has been the lack of the prime component of our data acquisition system, the Fluke 2290A Data logger. As stated in previous progress reports, the instrument was undergoing repairs suffered as a result of a lightning induced voltage surge on the power lines. The data logger was returned on November 1 and immediately put into service collecting temperature information. Presently this device is undergoing conversion (on site) to a higher band rate for faster data sampling. This should allow us to sample and store data at a rate of fifteen channels per second. Previously we were limited to three channels per second. This and other reasons restricted us to sampling intervals of four seconds when sampling five channels.

   The results presented in this section are from continuous recordings on a six-channel Sanborn strip-chart recorder. These recordings are used more for qualitative analysis than quantitative. It is easier to get a feel for the machine while observing the parameters being traced.

   Sections of runs are shown with accompanying explanations; comments have been made concerning specific observations.

Definitions of Symbols Used:

WV = wind velocity observed at the axis height from the house aneomometer, approximately 30 feet ENE of the wind turbine. Units: miles per hour.

Rpm = shaft rotational speed. This is actually the output voltage of a dc tachometer geared to the pinion shaft. It is geared to produce 23 volts at 167 Rpm. (See table below.)

B = blade pitch angle measured at the tip. This is actually the voltage of the feedback pot connected to the ball screw. Refer to the accompanying table for conversion between voltage and degrees.

FC = field current applied to the field winding. Units: dc amperes.

LV = load voltage measured at the terminals of the load. This is the line-to-neutral ac voltage. The load resistance per phase (wye-connected) is ten ohms.

Conversion Tables:

RPM	VOLTS
20	2.75
40	5.51
60	8.26
80	11.02
100	13.77
120	16.53
140	19.28
160	22.04
167	23.0
180	24.8

B (degrees)	VOLTS
90	4.93
40	3.34
30	3.03
20	2.72
10	2.40
5	2.25
0	2.09
-5	1.93
-6	1.90

Figure 1.3 11/2/77 Automatic Start-Up:

This strip chart section shows the automatic start-up of the WTG after it has been driven to face the wind. The wind speed was averaging five mph. It has been observed that in light winds (less than approximately 7 mph) the machine will not yaw about. This is primarily due to the friction of the yaw damper chains. Observations with the chains disconnected confirm this. Damping is required in higher winds, though, as without it the machine will yaw 360° if there is a sudden stoppage of the wind. This has been observed to happen with the yaw chain disconnected.

Blade pitching from 35 degrees to 4 degrees occurred when the shaft speed reached 20 Rpm.

Field current was automatically applied at a shaft speed of 37 Rpm. Due to the low winds the Rpm varied around the on-off speed of the field controller. This is why the field current cycled back and forth from zero to 0.42 amps.

Very little power was generated under these wind conditions as shown by the low load voltage, approximately 30 volts being the maximum attained.

Figure 1.4 Automatic Return to Start-Up Angle

In this case the wind decreased from an average at 10 mph to an average of 2.5 mph. The Rpm trace shows the same general decrease with a waveform shape similar to the wind waveform. This is to be expected with constant pitch angle operation.

The pitch angle was holding constant at zero degrees until the Rpm dropped below twenty. At this point the pitch controller increased the pitch angle to the start-up angles which had been set to thirty degrees.

The field current trace shows a transition of incremental changes in current level until the Rpm drops near the threshold Rpm for the field controller,

37 Rpm. Current cycling (on and off) begins until the Rpm drops below thirty-seven, at this point the field current is shut off.

The load voltage waveform is also similar in shape to the wind waveform. This is also to be expected as the voltage is a power function of the Rpm. The maximum voltage generated in this interval was 100 volts. Once the field current is zero, the voltage decays to a low value determined by the residual magnetism in the field iron and the rotor rpm.

Figure 1.5 11/2/77 Region 2 Operation: Light Breezy Winds

The average wind speed is still five mph. Due to this low wind speed and the cycling of the field current the shaft speed remained near 37 Rpm.

The pitch angle remained constant at four degrees as required for Region 2 operation.

The load voltage averaged 25 volts, for an average power output of 190 watts.

Figure 1.6 11/12/77 Region 2 Operation: Gentle Breeze Winds

In this case the wind was between 2.5 and 12 mph, averaging 7.5 mph. The similarity in waveforms between the wind speed, Rpm and load voltage is more readily seen. The Rpm and load voltage traces have their peaks and valleys more rounded than the wind speed trace. This is due to the inertia of the wind machine and the resulting lag in responding to the wind.

The pitch angle held constant at four degrees as the shaft speed remained between 20 Rpm and 167 Rpm.

The field current stayed mostly on and varied incrementally with the shaft speed.

The load voltage averaged 50 volts, the power output 750 watts.

As a result of the higher shaft speeds the load voltage stayed mainly between 100 and 300 volts. A maximum voltage of 330 volts was reached at a shaft speed of 173 Rpm. This maximum output of 32670 watts was the result of a wind gust to approximately thirty mph. Four other times the output reached or exceeded 300 volts, or 27000 watts.

Figure 1.10

These traces show the effect that an oscillating field current has on shaft Rpm and load voltage when the machine is operating in the higher Rpm range. This oscillation was not created intentionally. It appears to be the result of resonance in the field current feedback circuit. The frequency of oscillation is approximately four cycles per second. Comparing this with the calculated natural frequency of the mechanical systems (7.5 cps) it is clear that the machine cannot be allowed to operate in this manner. Corrective actions are being planned to alter the field controller.

The maximum output still reached a value of 275 volts, 22690 watts, in spite of this instability. Looking at the load voltage waveform, the amplitude of oscillation was very small indicating that the induced torque oscilations were also small. The maximum amplitude of the Rpm oscillation was $\pm$ 5 Rpm centered at 140 Rpm.

Figures 1.11 and 1.12

Figures 1.11 and 1.12 show certain data points plotted along with the predicted curves of power output. These graphs show:

1) Even though the data points seem to cluster around the predicted curves, there are some large variations. Some of the variations are as much as 50% over or under the predicted value. These were most likely caused by the nature of the wind and the settings of

the pitch angle and excitation.

2) Rated power was exceeded many times. The maximum power 32690 watts, (30.7% overrated), occurred at a value of 173 Rpm, 3.6% overrated shaft speed. The machine had entered Region 3 operation starting at a pitch angle of four degrees and increasing to eighteen before returning to four. (These traces can be seen in Figure 1.9 occurring on November 27, 1977 at approximately 0810 hours.)

For an overspeed of this magnitude the predicted power level would be 27000 watts. The value has been recorded under the same conditions of pitch angle excitation and shaft speed. The exceptions were the maximum pitch angle obtained of 16°, and the wind speed of the gust. The differences between these two cases accounted for the 21% greater output over predicted.

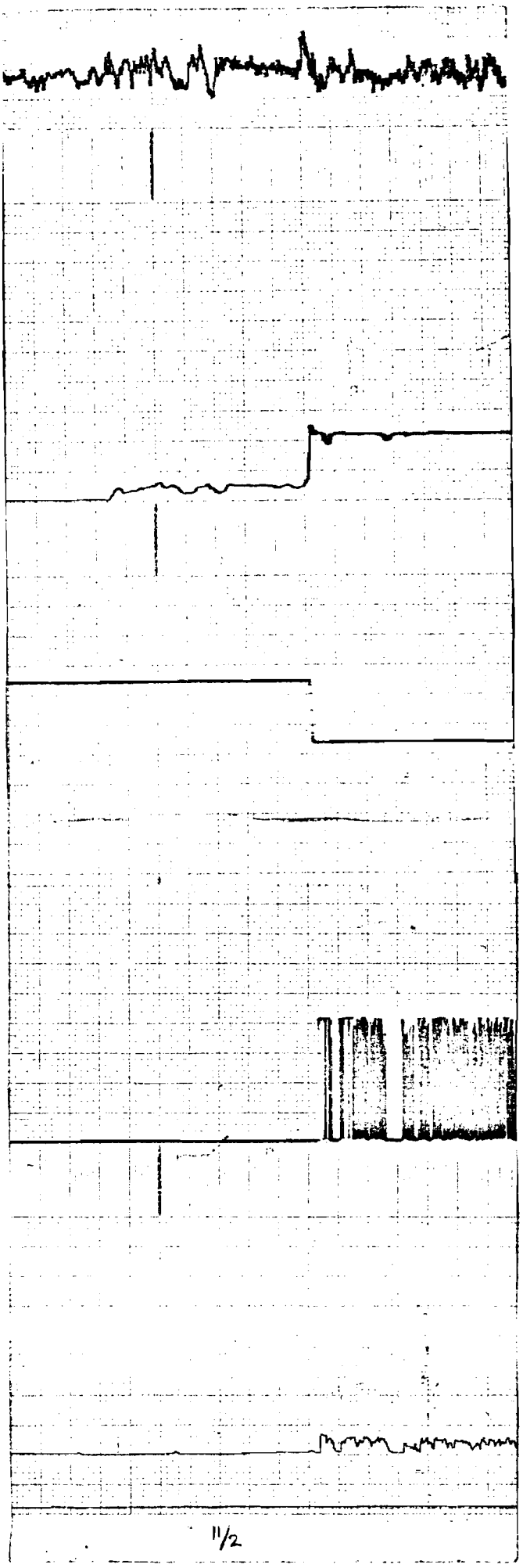


Figure 1.3

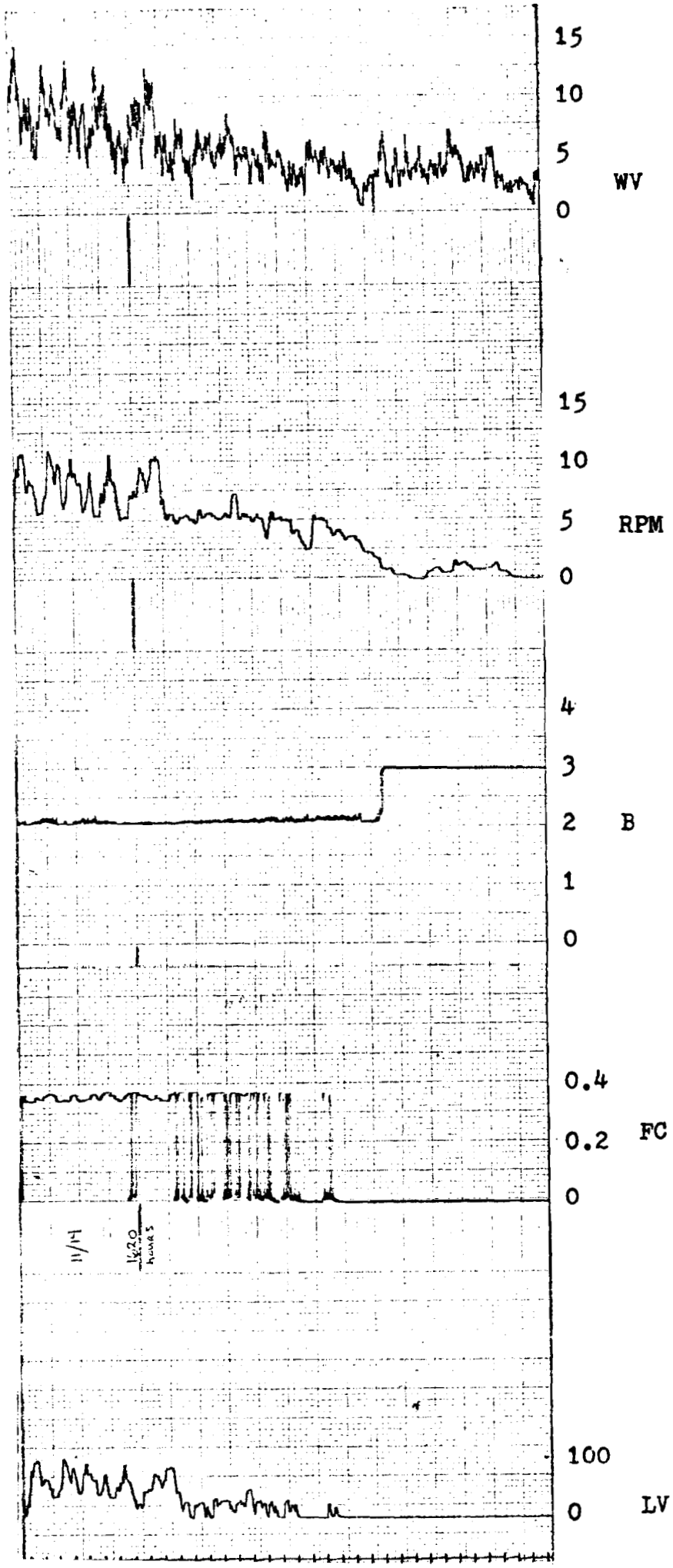


Figure 1.4

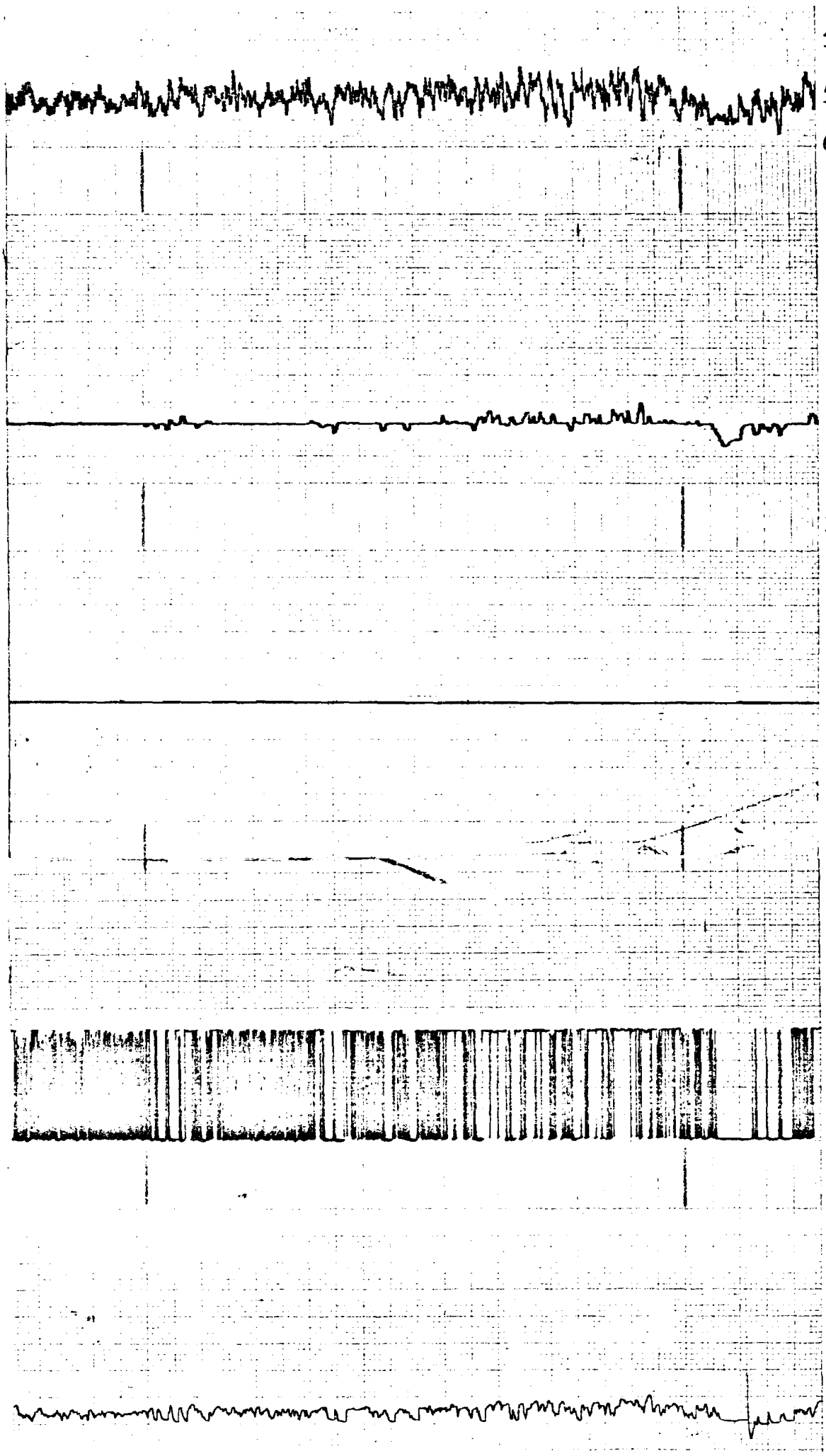


Figure 1.

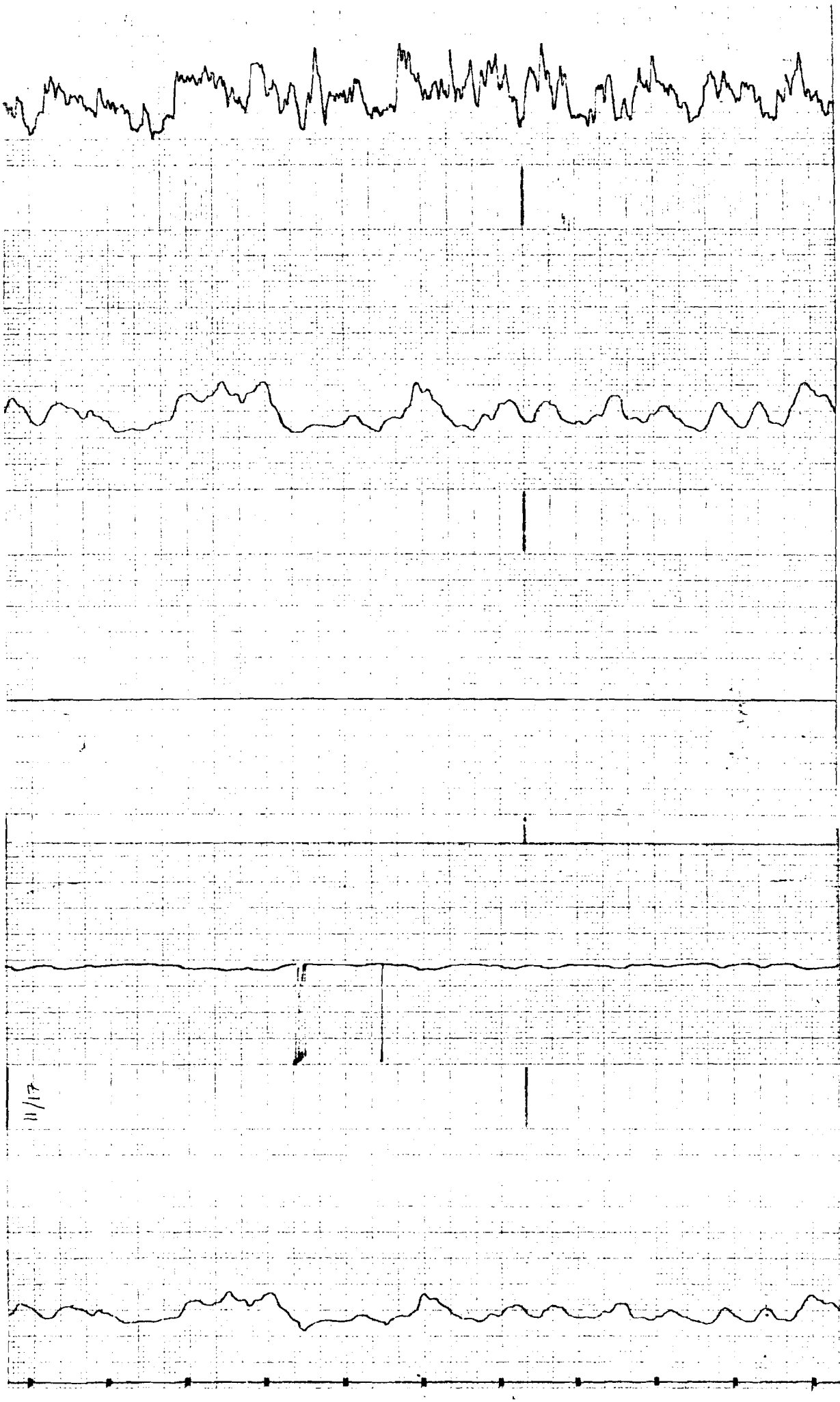


Fig.1.6

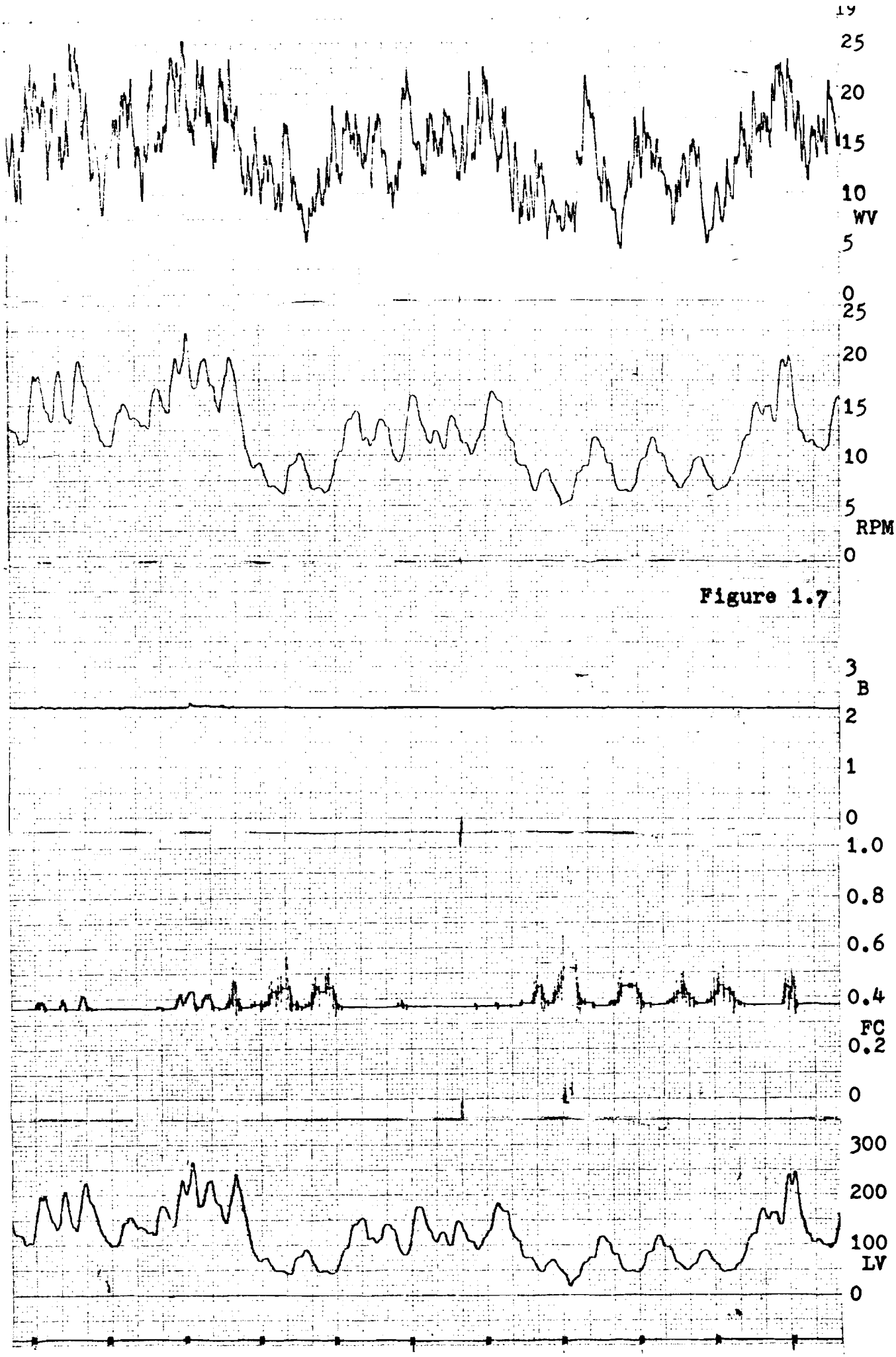

25
20
15
10
WV
5
0
25
20
15
10
5
RPM
0
3
B
2
1
0
1.0
0.8
0.6
0.4
FC
0.2
0
300
200
100
LV
0

Figure 1.7

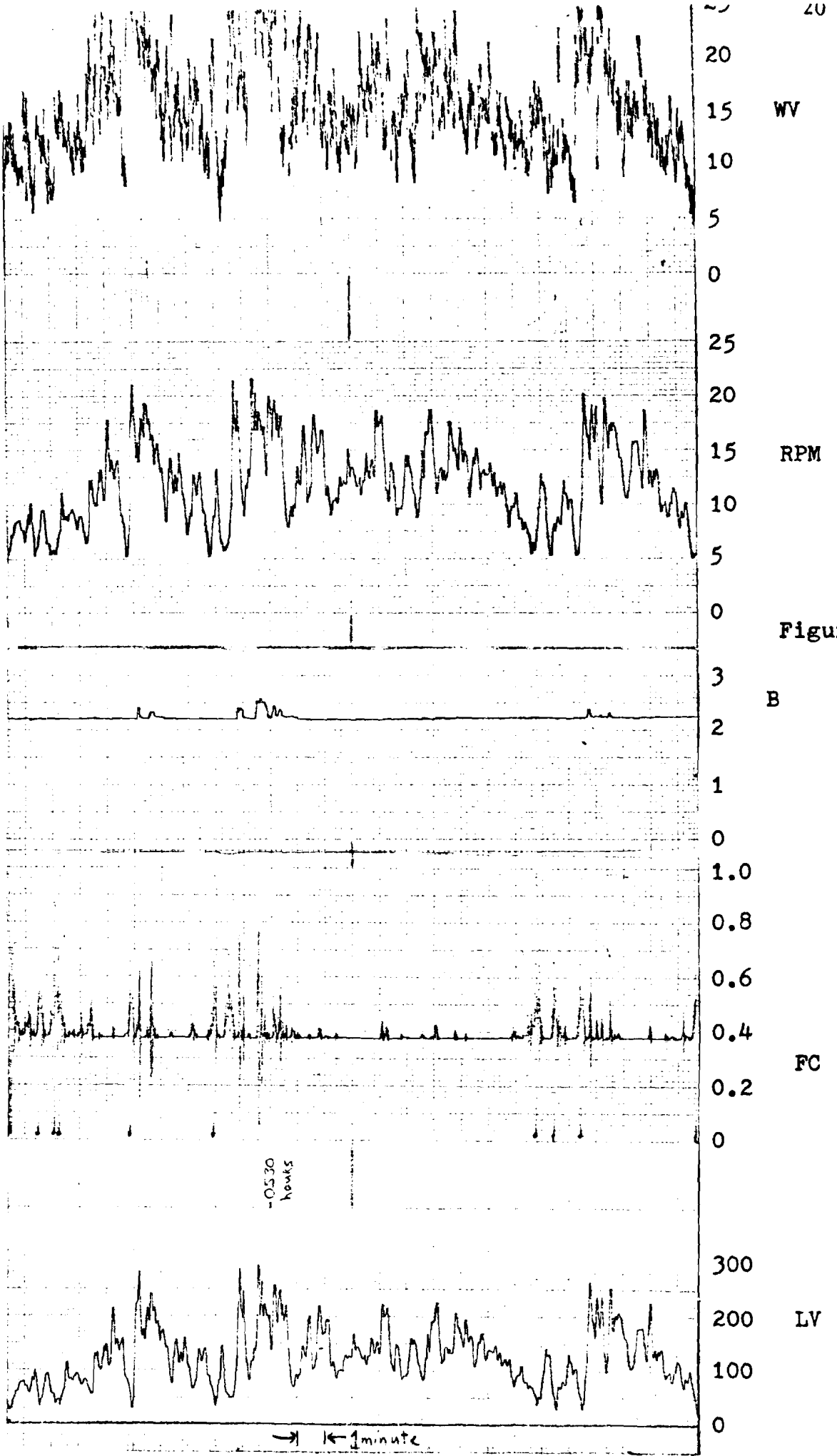

20
15
10
5
0
WV
25
20
15
10
5
0
RPM
3
2
1
0
B
1.0
0.8
0.6
0.4
0.2
0
FC
-0530 hours
300
200
100
0
LV
1minute

Figure 1.8

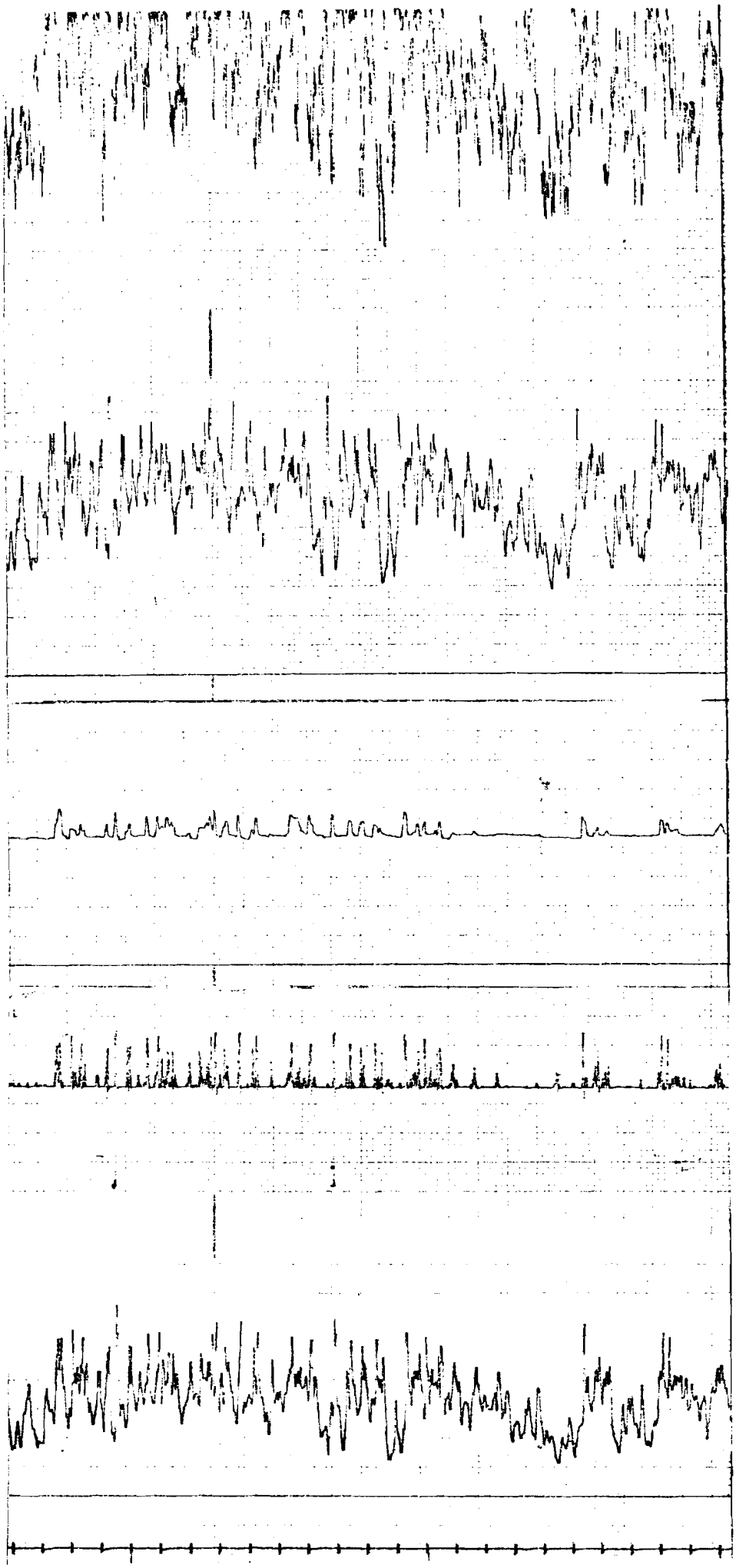

25
20
15
WV
10
5
0
25
20
15
10
RPM
5
0
3
2
B
1
0
0.6
0.4
FC
0.2
0
400
300
200
LV
100
0

Figure 1.9

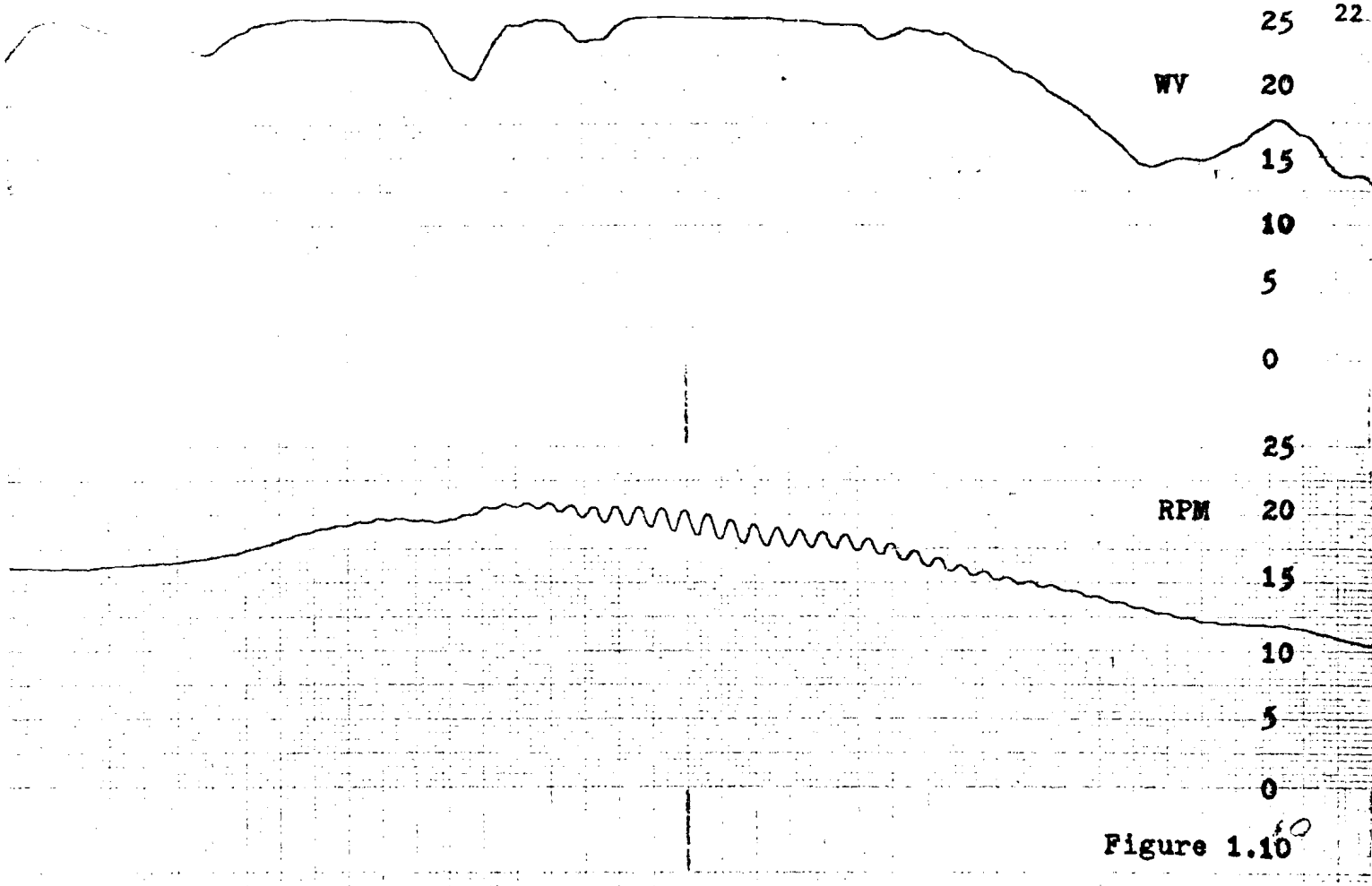
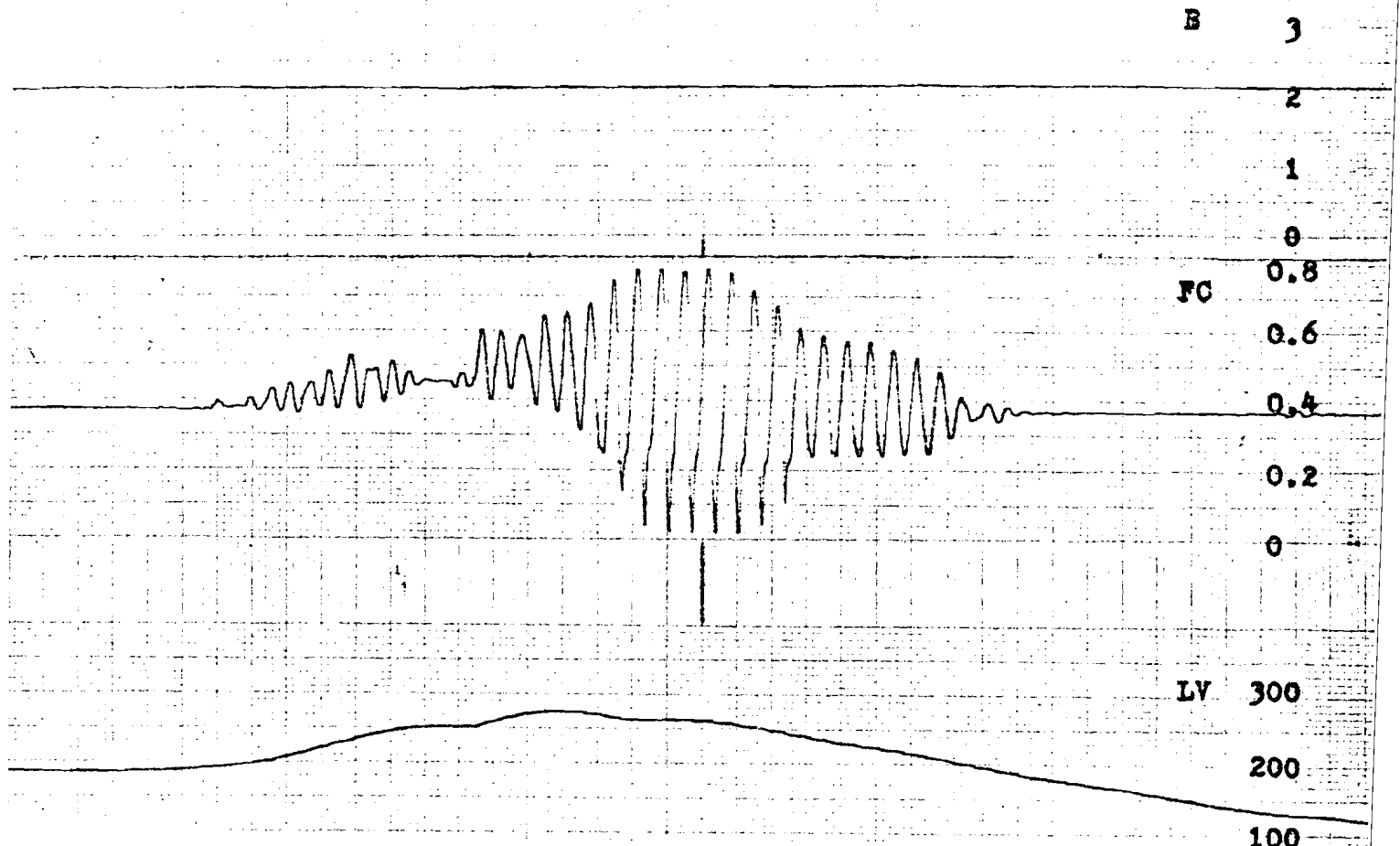

WV
25
20
15
10
5
0
RPM
25
20
15
10
5
0

Figure 1.10


B
3
2
1
0
FC
0.8
0.6
0.4
0.2
0
LV
300
200
100

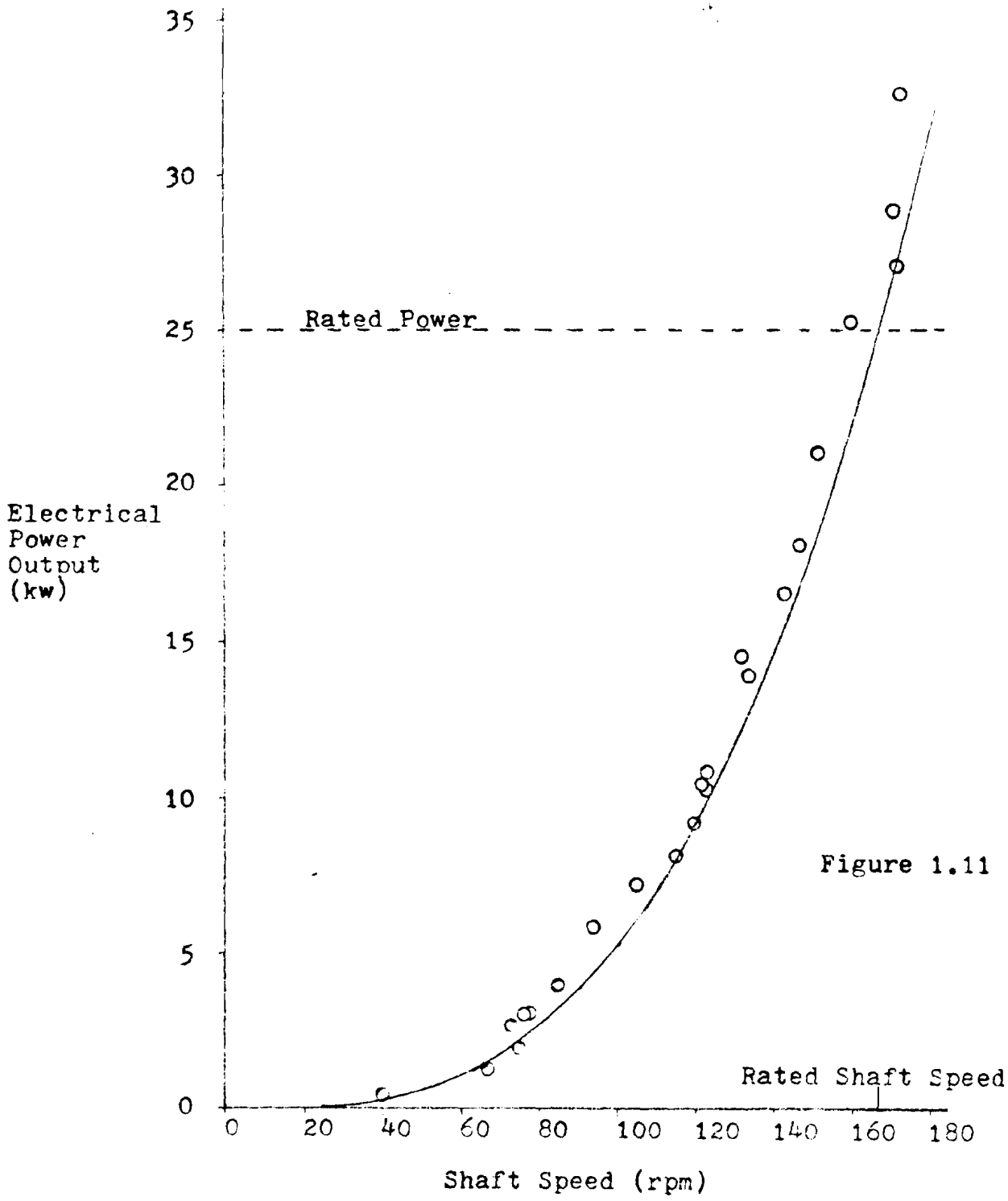

35
30
25
20
15
10
5
0
Rated Power
Electrical
Power
Output
(kw)
Rated Shaft Speed
0
20
40
60
80
100
120
140
160
180
Shaft Speed (rpm)

Figure 1.11

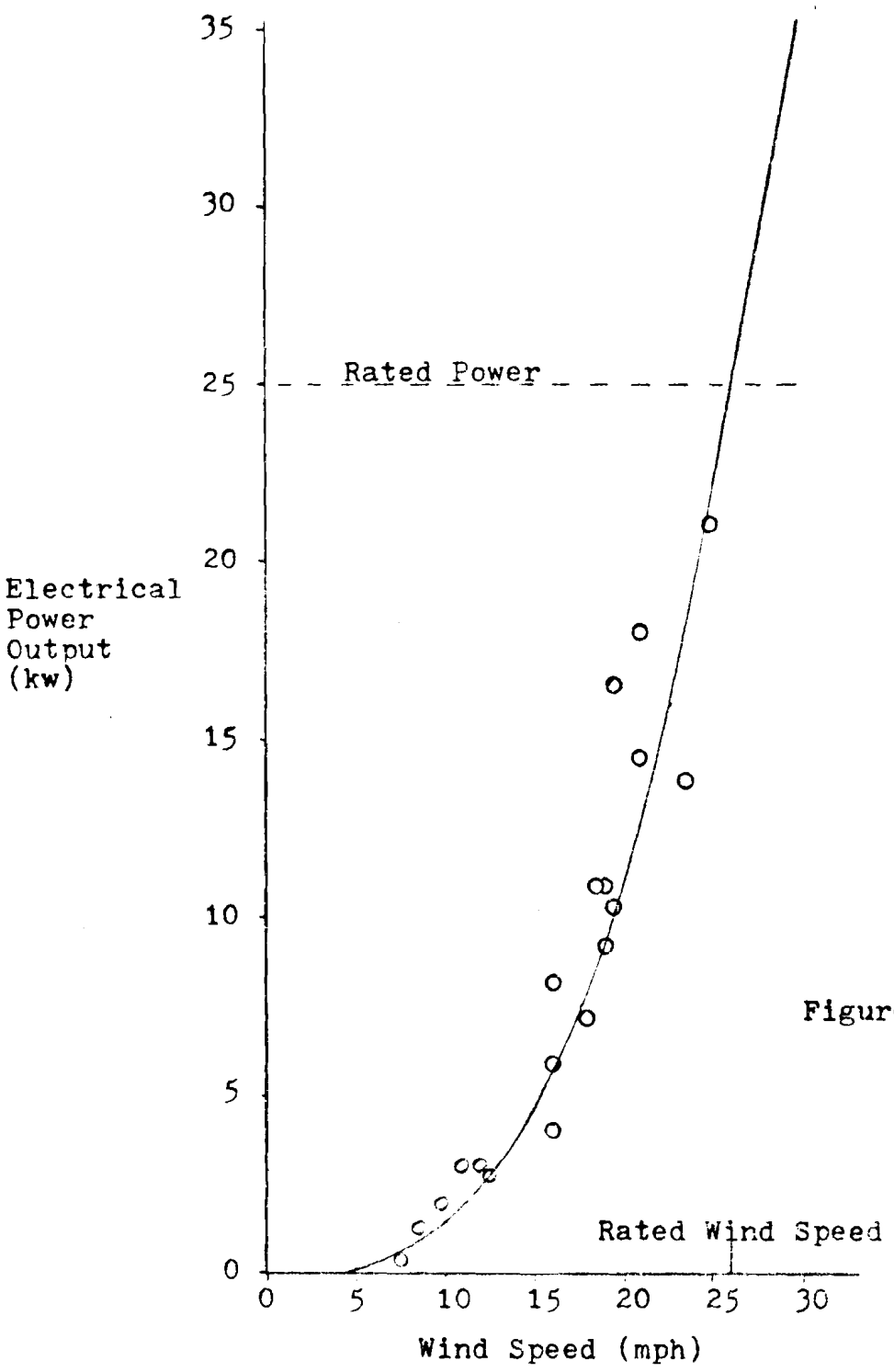

35
30
25
20
15
10
5
0
Rated Power
Electrical
Power
Output
(kw)
Rated Wind Speed
0
5
10
15
20
25
30
Wind Speed (mph)

Figure 1.12

Data Points Plotted:

	Speed Wind (mph)	Shaft Speed (RPM) ± 2 RPM	Electrical Power Output (kW)	Tip-Speed Ratio	Pitch Angle ± 2° degrees	Field Current Amps	Comments
1	7.5	40	.370	6.2	0	0.49 on-off	± 0.5 pmh for 30 sec
2	8.5	67	1.270	9.1	4	0.37	± 0.5 mph for 8 sec
3	9.7	75	1.920	8.9	4	0.36	constant for 8 sec
4	11	78	3.000	8.2	0	0.37	± 1.5 mph for 24 sec
5	12	76	3.000	7.4	0	0.36	± 2 mph for 30 sec
6	12.5	73	2.710	6.7	0	0.37	± 2 mph for 24 sec
7	16.0	85	3.970	6.2	4	0.37	peak
8	16.0	94	5.880	6.8	4	0.38	peak
9	16.0	115	8.170	8.3	4	0.37	± 2 mph for 30 sec
10	18.0	105	7.210	6.8	4	0.37	peak
11	18.5	123	10.830	7.7	0	0.38	± 2 mph for 18 sec
12	19.0	120	9.190	7.3	4	0.37	peak
13	19.0	123	10.830	7.5	4	0.37	± 1.5 mph for 30 sec
14	19.5	123	10.270	7.3	0	0.37	± 4 mph for 30 sec
15	19.5	122	10.350	7.2	0	0.37	± 3 mph for 30 sec
16	19.5	143	16.570	8.5	0	0.46	peak
17	21.0	132	14.520	7.3	0	0.41	peak
18	21.0	147	18.000	8.1	0	0.46	peak
19	23.5	134	13.870	6.6	4	0.41	peak
20	24.8	152	21.070	7.1	4	osc.	peak
21	25+	160	25.230	-	4 to 16	0.55	peak
22	25+	161	25.230	-	4	Osc.	peak
23	25+	171	28.830	-	4 to 10	osc.	peak
24	25+	172	27.000	-	4 to 18	0.55 off	peak
25	25+	173	32.670	-	4 to 16	0.55 off	peak

Data taken from the strip chart traces. Runs conducted from 11th to 27th of November, 1977

These particular points were selected to give a wide range of Rpm and of wind speed.

The wind speed denoted by 25+ indicates that the wind exceeded 25 mph but due to the recorder setting could not be measured. These points were recorded when the machine was operating unattended.