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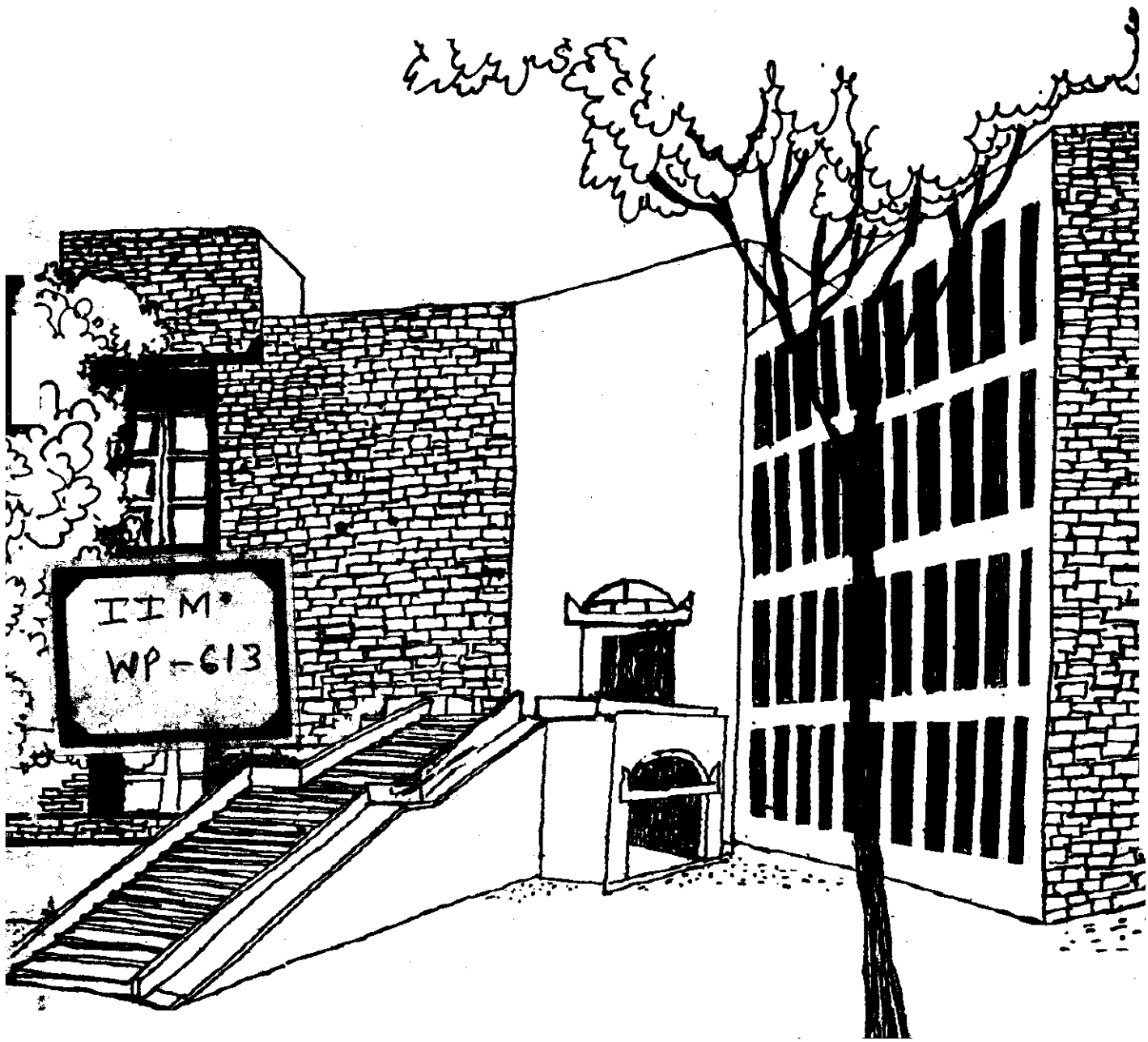

RELIABILITY ANALYSIS OF APOLY-12-PU-500 WINDMILLS

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ABSTRACT

Breakdown data of APOLY-12-PU-500 windmills of Gujarat has been analysed. Bartlett's test suggested the plausibility of failure being exponentially distributed. The mean-time-between-failures (MTBF) was estimated, expected failure frequency computed. The observed and expected frequencies are close enough, as indicated by the goodness-of-fit test. The MTBF worked out to 283 hrs. which in Gujarat conditions could mean at the most 2 months of working. The reliability of this model thus is low. Repair costs will be higher than expected by the designers.

INTRODUCTION

The Commission for Additional Sources of Energy (CASE) started nation-wide windmill demonstration project in 1981. It supplied APOLY-12-PU-500 windmills free of cost to different states. Thirty three windmills were allotted to Gujarat for the year 1981-82 and 50 for 1982-83. By the end of 1983, 32 windmills had been installed. Fig. (1) shows diagram of APOLY-12-PU-500 windmill.

A little after the installations, a system of monitoring of field performance was introduced. Trained mechanics were appointed and stationed at or near various installations to look after the windmills. They also

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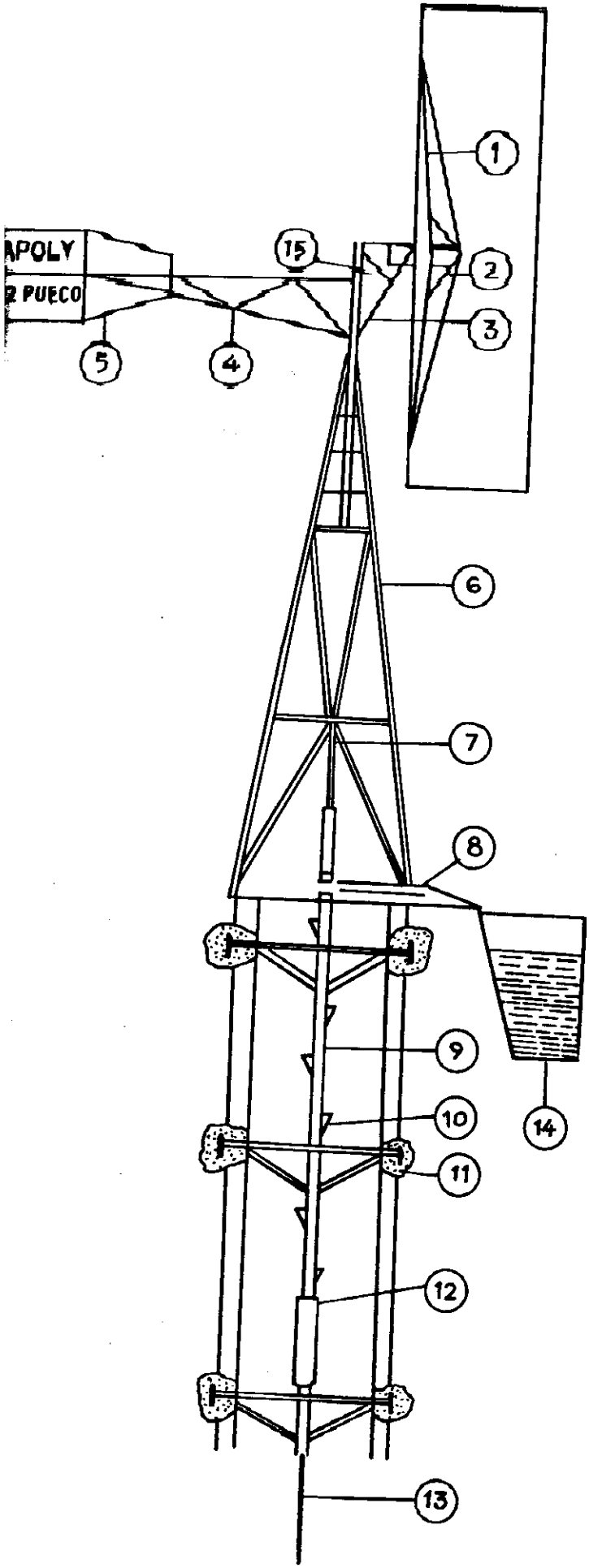


1 ROTOR
2 SHAFT
3 HEAD CONSTRUCTION
4 TAIL
5 TAIL VANE
6 TOWER
7 PUMP ROD
8 DISCHARGE PIPE
9 DELIVERY PIPE
10 STEPS
11 BRIDGE
12 PUMP
13 SUCTION PIPE
14 STORAGE TANK
15 HELP VANE SECURITY SYSTEM

TOWER HEIGHT : 7 m
BASE DIMENSION : 2.20 m^2
ROTOR DIAMETER : 5 m
NUMBER OF BLADES : 12
CUT-IN WIND SPEED : 2.5 m/Sec.
CUT-OUT WIND SPEED : 10 m/Sec.
TIP SPEED RATIO : 2
TOTAL WEIGHT : 450 Kgs (approx.)
TRANSMISSION SYSTEM : CRANK MECHANIS
PUMP : SINGLE ACTING RECIPROCATING TY
SECURITY SYSTEM : AUTOMATIC BY TAIL VA

Fig. 1 : Side View of the APOLY-12-PU-500 Windmill

were to record daily working of the windmills and send consolidated reports each week to the headquarters in Ahmedabad. This system was being gradually expanded. At the time of the study, reports were being received from nearly half of the installations. The data on frequency of breakdown analysed here, was taken from the weekly reports. Some of the available reports were of very recent origin and some were not regular. Reports on 14 installations only, therefore, had been used here in analysis.

DATA

The time at which unscheduled shutdowns (requiring major repairs, replacement of parts) occurred is given in a Table 1 (a). The time between successive shutdowns is also shown in Table 1 (a).

ANALYSIS

Visual examination suggested the possibilities that the underlying distribution may be exponential. Bartlett's test[2] was accordingly performed to test the hypothesis of exponentiality.

$$B_r = \frac{2r\left[\ln\left(\frac{tr}{r}\right) - \frac{1}{r}\left(\sum_{i=1}^{r} \ln x_i\right)\right]}{1 + (r+1)/6r}$$

where

B_r is the test statistic

r = total number of failures (32)

x_i = random variable representing time to failure (Table 1 (b) shows the x_i values)

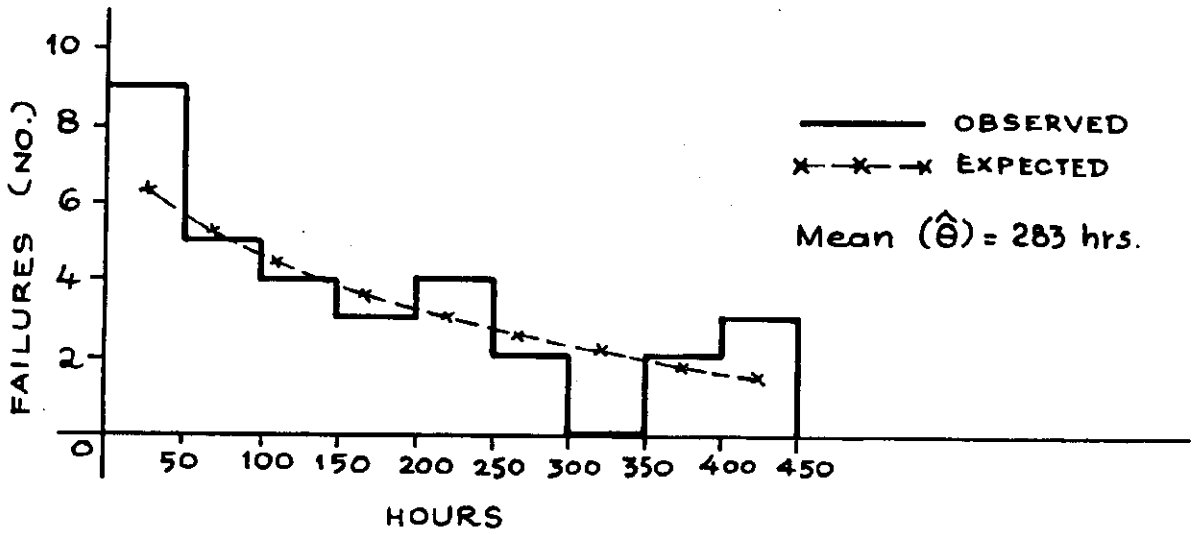
TABLE 1(a) : HISTORY OF SHUTDOWNS

Wind Mill No.	Hours at Shutdown (Cumulative)	Hours between Shutdown
01	224, 630, 875, 900	224, 406, 245, 25
02	357, 413, 644, 763, 847, 889, 924	357, 56, 231, 119, 84, 42, 35
03	854 (unfailed)	-
04	74, 221, 242, 314	74, 147, 21, 72
05	125, 143, 402	125, 18, 259
06	882 (unfailed)	-
07	447, 804, 832, 867, 888, 1049	447, 357, 28, 35, 21, 161
08	416 (unfailed)	-
09	546 (unfailed)	-
10	840 (unfailed)	-
11	175, 399, 812	175, 224, 413
12	70, 338, 373	70, 268, 35
13	456 (unfailed)	-
14	161, 301	161, 140

Source: Weekly Repor

TABLE 1 (b) : TIME TO OBTAIN SHUTDOWNS

Time (hrs.)		No. of windmills operating	Total time (hrs.)	Time to obtain shutdown (hrs.)	Time (hrs.)		No. of windmills operating	Total time (hrs.)	Time to obtain shutdowns (hrs.)
70		14	980	980	456	suspended	9	5910	-
74		14	1036	56	546	suspended	8	6630	-
125		14	1750	714	630		7	7218	1389
143		14	2002	252	644		7	7316	98
161		14	2254	252	763		7	8149	833
175		14	2450	196	804		7	8436	287
221		14	3094	644	812	failed and sus-	7	8492	56
224		14	3136	42	832	pended	6	8612	120
242		14	3388	252	840	suspended	6	8660	-
301	failed and suspended	14	4214	826	847		5	8695	83
314	failed and suspended	13	4383	169	854	suspended	5	8730	-
338		12	4671	288	867		4	8732	87
357		12	4899	228	875		4	8814	32
373	failed and suspended	12	5091	192	882	suspended	4	8842	-
399		11	5377	286	888		3	8860	46
402	failed and suspended	11	5410	33	889		3	8863	3
413		10	5520	110	900	failed and suspended	3	8896	33
416	suspended	10	5550	-	924	failed and suspended	2	8944	48
447		9	5829	309	1024	failed and suspended	1	9069	125



Range (hrs.)	Observed failures (No.)	Expected Failures (No.)	
0-100	14	11.3	df = 2
100-200	7	7.9	χ^2 = 1.14 (calculated)
200-300	6	5.6	$\chi^2_{.5}$ = 1.38 (Tabulated)
above 300*	11*	13.2	
Total	38	38.0	

* includes those (6) that were in unfailed state.

Fig. 2 Failure Distribution

$$t_r = \sum_{i}^{r} x_i = 9069$$

$$B_r = 36$$

$$\chi^2_{.95,\ 30} = 18.49$$

$$\chi^2_{.05,\ 30} = 43.77$$

Thus, the hypothesis of exponentiality can not be rejected. Estimated mean time between failures

$$\hat{\theta} = \frac{9069}{32} = 283.41 \approx 283$$

The χ^2 test for goodness-of-fit indicates that the observed and the expected failure frequency are fairly close.

The failure of pump components - piston and valves - contributed most to the shutdowns. The transmission elements - connecting rod, crank and crankpin - were the next.

Sinha[3] had indicated in his paper that the cost per unit swept area of this windmill is among the lowest. Commenting on this claim, Tewari[4] had noted "It is not unlikely that this cost reduction has been achieved at the expense of reliability and increased maintenance support and this needs to be examined. It is claimed that multivane windmills of imported origin

do not require any maintenance except annual oiling and occasional change of pump washer. On the other hand, an appropriate technology design such as APOLY might require significant maintenance support as we shall probably hear under the case study session from IIMT." The field data from Gujarat has corraborated Tewari's observations.

CONCLUSIONS

a) The MTBF of APOLY-12-PU-500 was estimated at 283 hrs. The possible daily hours of operation depend on the wind regime. The trial windmills in Gujarat logged in on average of 5 hours a day. On this basis the frequency of shutdowns requiring major repair works out to less than 2 months. Pump components contributed most to the shutdowns followed by transmission elements. There could also have been faulty installations poor aligument etc.

b) The machine does not appear to have been tested for reliability, before popularization. This normally is an integral part of design function. It should particularly have been so since windmills normal are in remote areas where attending to repairs is time consuming. It is necessary to put this model to through reliability tests before further multiplication.

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