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Reliability Analysis of Electro-Hydraulic Based Auto-Leveling System for Mobile Platform

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Abstract— ***This paper deals with the reliability analysis of Auto-levelling system of mobile platform used for specific application (e.g. ground boring machine, mobile antenna system for communication & mechanism for weapon operation etc.). For these applications, there is an operational requirement to provide stability and precise levelling within (± 6 min) through auto levelling system provided to the platform. It is observed that though such systems have been designed to perform the task, there are two major causes that may reduce the reliability of the system :- (i) Due to complex hydraulic, mechanical, electronic system including software. (ii)Oil contamination which may even lead to failure of the system. This paper restricts the reliability analysis to the hydraulic system and mechanical components. Fault Tree Analysis (FTA) and Failure Mode & Effect Analysis (FMEA) are used as tools for systematization of reliability parameters and determining the criticality of the components in the design stage.***

Index Terms— **Electro-hydraulic system, Auto-levelling, Reliability Analysis, Fault Tree Analysis, Failure Mode and Effect Analysis.**

I. INTRODUCTION

The mobile platforms are used for critical application hence the reliability of overall system should guarantee the main functions, such as, force, speed and accuracy etc. Also it should have low operational/maintenance cost and provide safety to equipments and personnel. Further, it is observed that though the hydraulic system looks simple, it is very sensitive to oil contamination. As per the literature survey, approximately 70% of failures of hydraulic systems are caused due to oil contamination [1]. Electro-hydraulic system is used for Auto-levelling of Mobile platform due to the advantages like force multiplication by designing the driving piston, high power density, high acceleration capability, less preparation time and safe & mature technology. Assessment of reliability in such case needs systematic procedure. The reliability analysis is presented in following sections, i.e

(i) Description of Auto-levelling system, having number of sub-systems.

(ii) Failure Mode & Effect and Criticality Analysis (FMECA)

(iii) Fault Tree Analysis (FTA)

II. DESCRIPTION OF AUTO LEVELLING SYSTEM

The levelling of platform is done using four number of outrigger cylinders integrated on the vehicle platform. These outrigger actuators are operated through electro-hydraulic system consisting of proportional solenoid valves, which receives signals through level sensor and levelling algorithm. The hydraulic power required to operate outrigger cylinder is given through a hydraulic power pack. There are two pumps; one operates from vehicle Power Take-Off (PTO) and another through electric motor. The salient features of hydraulic systems are:

(i) Redundancy in hydraulic pump
(ii) Strainer in pump inlet
(iii) Filters in pressure and release valves
(iv) Off line filtration system with contamination monitor to reduce system failure due to oil contamination

This process continues till the platform is levelled with specific accuracy of + 6 min. The block diagram [2] of Auto Levelling system is shown in Fig. 1 and Hydraulic System in Fig. No. 2 The major system for Auto-levelling consists of following sub-systems & components

(i) Hydraulic system to actuate outrigger cylinders:
- Hydraulic power pack
- Proportional Direction Control Valves
- Outriggers, with pilot operated check valve

(ii) Control signal consists of power supply, software (algorithm) and hardware. This will supply the power to proportional valve for operation of outrigger cylinders.

(iii) Platform tilt angle indication system consists of level sensors, A/D converter and power supply. Two sensors have been used, one for longitudinal and other for lateral shift of the platform. Once the platform is levelled, the outrigger cylinder movement is locked using hydraulic motor driven mechanical sleeves to avoid creep of platform. Figure 1& 2 are shown in Appendix.

III. FAILURE MODE & EFFECT AND CRITICALITY ANALYSIS (FMECA) OF AUTO-LEVELLING SYSTEM

It is the first step for working of the system reliability analysis. During the analysis, the major components, sub-systems and assemblies are reviewed to identify various failure modes. The objective is to identify all possible failure modes, causes and effects of such failures. Such analysis which were done successfully for important projects, e.g. Chemical Mixing Equipment [3], RML

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Vehicle [4] & Vehicle Mounted Hydraulic Crane [5] and STUK [6] describe the FMEA procedure for safety of critical software, implemented for platform used in an industrial automation system.

In the present study, Criticality analysis based on FMEA has been done through `Risk Priority Number' (RPN) giving appropriate values of Occurrence, Safety and Detection in the scale ranging from 1 to 10, respectively. Table 1 shows details of FMEA for Auto-levelling System. In this, Reliability Confidence Index is considered as 85%. Hence, the threshold value of RPN value comes out to be 150 as advocated by D.H. Stamatis [7].Procedure for performing FMEA is referred as per MIL-Std.1629 A [8]. It is seen from the table that major failures (where RPN is more than 150) are due to Oil Contamination, Pressure Line Filter, and Level Sensor & Software. However, with proper control of contamination e.g. provision of Off-line filtration system will reduce the hydraulic system failure. Similarly, proper selection of filter & components will improve the reliability of the system. Figure 2&3 and Table 1& 2 are shown in Appendix.

A. *Mean & Standard Deviation*

From the RPN values shown in Table 1 the mean & standard deviations worked out & shown in Table 2.From the Table 2, it is seen that mean value is 145 & Standard deviation is 46. The distribution of 13 nos RPN values, here, shows the extreme asymmetrical distribution. It is better to use median, instead of mean. This is done after arranging data in ascending order to take the mid value. In this case the median is 180, which could be taken as "Thresholding" value for determining the criticality of the system. All sub-systems having RPN value above 180 are hyper critical and their design or performance or both may be reviewed and necessary precautionary steps undertaken to make the overall system more reliable.

IV. Fault Tree Analysis (FTA) of Auto-Levelling System

It is a deductive technique for determining the causes of system failure & the association reliability parameters. The Fault tree provides a visual representation of the structure of the system by expressing a particular failure in terms of components failures. Clifton A Ericson mentioned that the Boeing Company used FTA tool to design the reliability of Missile System and commercial aircrafts [9]. The fault tree diagram for auto-levelling system is shown in Fig. 3. The symbols used for construction of Fault tree are as per the FTA handbook [10]. The reliability analysis is carried out for each major sub-system i.e. hydraulic system, control signal & platform tilt angle. The data assumed for failure rates of various elements of Auto levelling system are as follows:

$$\lambda_1 = \lambda_2 = \lambda_5 = \lambda_6 = \lambda_{12} = \lambda_{13} = 0.004 / hr$$

$$\lambda_3 = \lambda_4 = \lambda_7 = \lambda_8 = \lambda_9 = \lambda_{10} = \lambda_{11} = \lambda_{14} = \lambda_{15} = \lambda_{16} = \lambda_{17} = 0.005 / hr$$

The failure rates are added while obtaining Or Gate analysis, hence subsequent level failure rates are obtained as follows:

$$\lambda_{T1} = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 = 0.002 / hr$$

$$\lambda_{T2} = 0.017 / hr$$

$$\lambda_{T4} = 0.018 / hr$$

$$\lambda_{T5} = 0.020 / hr$$

$$\lambda_{T6} = 0.025 / hr$$

$$\lambda_{T8} = 0.009 / hr$$

$$\lambda_{T9} = 0.015 / hr$$

Assuming mission time for each element as 1 hour of continuous working, for λ_{T3} equation (1) is given as follows [11]

$$\lambda_{T3} = \frac{\lambda_{T1}(Z_{T1} - 1) + \lambda_{T2}(Z_{T2} - 1)}{Z_{T1} Z_{T2} - 1} ----(1)$$

$$\frac{1}{Z_J} = (1 - e^{-\lambda jt}) \quad , \quad Z_J = \frac{1}{(1 - e^{-\lambda jt})}$$

$$Z_{T1} = \frac{1}{(1 - e^{-0.22})} = 5.06$$

$$Z_{T2} = \frac{1}{(1 - e^{-0.17})} = 6.40$$

$$\lambda_{T3} = \frac{0.022(4.06 - 1) + 0.017(5.40 - 1)}{5.06 \times 6.40 - 1} = 0.006 / hr$$

$$\lambda_{T7} = \lambda_{T3} + \lambda_{T4} + \lambda_{T6} = 0.046 / hr$$

Following the same procedure λ_{T0} can be calculated as

$$\lambda_{T0} = \lambda_{T7} + \lambda_{T8} + \lambda_{T9} = 0.070 / hr$$

Hence, the overall failure rate of the system= 0.070/hr

Reliability of Auto-levelling system (R_{AL}) is obtained by following equation $R_{AL} = e^{-0.07t}$

Assuming mission time for Auto- levelling is Maximum 3 Minutes (0.05 hr.) the reliability of system is obtained as

$R_{AL} = e^{-0.07 \times 0.05} = 0.99650$

Thus FMEA & FTA are the powerful tools for reliability analysis.

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V. CONCLUSION

For carrying out the reliability analysis of Auto-Leveling system for Mobile Platform FMECA & FTA tools have been used & the result obtained during the trials show the high degree of viability with the theoretical analysis.

(i)The reliability of Auto-levelling system using FTA for mission time of 3 min is worked out 99.65%, which is very high for such complex system.

(ii) Oil contamination reduces the reliability. However, the reliability can be improved by proper control & monitoring of oil contamination.

(iii) FMEA determines all possible ways the equipment can fail & the effect of such failure on the system. It focuses on the part of which the system is comprised.

(iv) FTA determines the possible causes of the system failure and failure rate at various levels. It focuses on the total system failure and hence helps in finding reliability of system.

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APPENDIX

Fig.1.Block Diagram for Auto Levelling system for Mobile Platform

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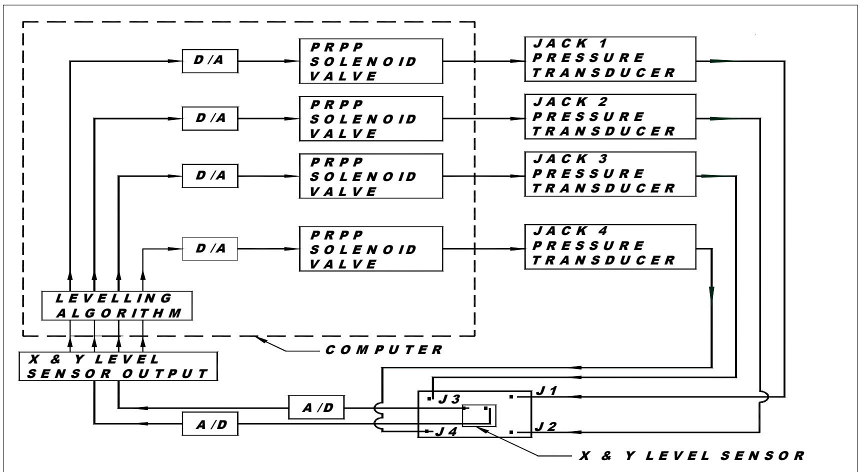
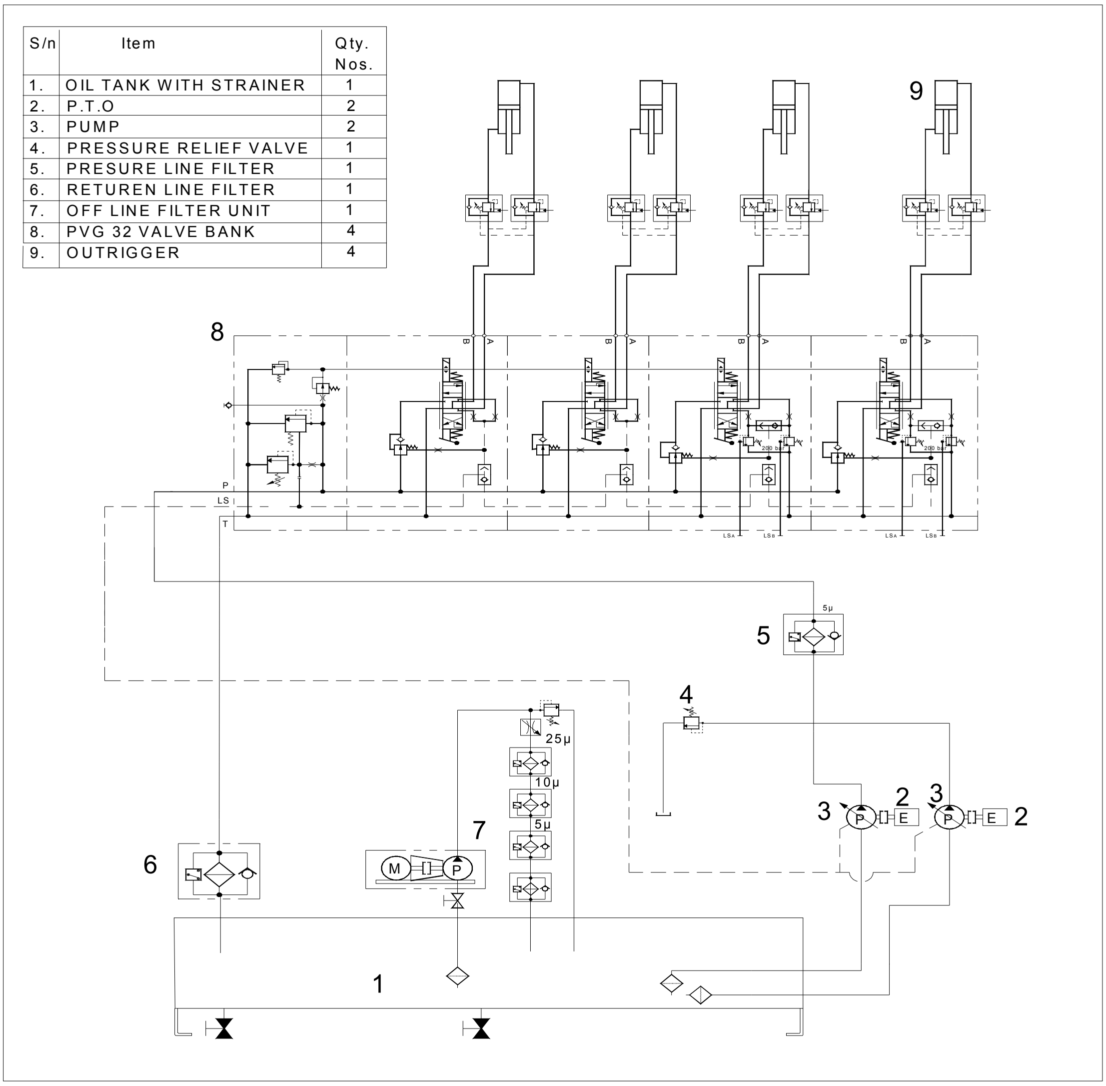


FIG. 1 - BLOCK DIAGRAM FOR AUTO LEVELING SYSTEM FOR MOBILE PLATFORM

Fig.2 Hydraulic System for Autolevelling



S/n	Item	Qty. Nos.
1.	OIL TANK WITH STRAINER	1
2.	P.T.O	2
3.	PUMP	2
4.	PRESSURE RELIEF VALVE	1
5.	PRESURE LINE FILTER	1
6.	RETUREN LINE FILTER	1
7.	OFF LINE FILTER UNIT	1
8.	PVG 32 VALVE BANK	4
9.	OUTRIGGER	4

.

Fig

Table 1. FMEA for Auto-Levelling System

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Components/ Systems	Function	Failure Mode	Effect of Failure	Causes of Failure	Occurrence of failure	Severity	Detection	RPN	Corrective action
Motor / P.T.O.	To operate the pump	Mal-functioning	Hydraulic Pump will not operate	Fluctuation in power supply /engine RPM	2	9	6	108	OK
Pump	Source of Hydraulic Power	Not delivering oil properly	Hydraulic System will not operate / Slow operation	High contamination level of oil	5	9	4	180	Providing monitoring of filter prior to oil in
				Mech. failure of bearing	2	9	4	72	OK
Pressure line filter	To filter oil / remove contaminants	Oil supply irregular / stopped	Slow movement of outrigger cylinder	Clogging of filter due to contaminant of oil	4	9	5	180	To control and monitor oil contamination
				Rupture of filter element	2	9	6	108	OK
Proportional direction control valve	To supply oil to outrigger cylinder	Oil supply irregular / stopped	No / Slow movement of outrigger cylinder	High contamination level of oil	5	9	4	180	To control and monitor oil contamination
				No power supply	2	9	5	90	OK
Outrigger cylinder	To level the platform	No / Irregular oil supply	Levelling of platform not possible	Pilot operated valve not functioning	2	9	4	72	OK
				Leakage through seals	3	8	6	144	Seals to be changed
Level sensor for Platform tilt angle	To indicate platform tilt angle	Malfunctioning	No proper levelling of platform	Improper power supply	3	9	7	189	Ensure proper power supply
				Not functioning of A/D converter	3	9	7	189	Use ruggedized & proven components
Control signals for proportional DC valve	To operate outrigger cylinder proportional to tilt angle of platform	Erratic signals / non signals	Valve will not function / properly function	Not functioning of D/A converter	3	9	7	189	Use ruggedized & proven components
				Software not functioning	3	9	7	189	Improve software & do periodical checking

Table 2. Mean and Std. deviation Calculation Table For RPN

S. No	RPN (Xi)	(X-Xi)	$(X\text{-}Xi)^2$
1	108	-37	1369

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2	180	+ 35	1225
3	72	-73	5329
4	180	+35	1225
5	108	-37	1369
6	180	+35	1225
7	90	-55	3025
8	72	-73	5329
9	144	-1	1
10	189	+44	1936
11	189	+44	1936
12	189	+44	1936
13	189	+44	1936
	Σ=1890		Σ =27841
	X= 1890/13=145		$\sigma=\sqrt{(\frac{(x-xi)^2}{13}}$=46.27

Fig 3. FTA for Auto-Levelling of Mobile Platform