A NOVEL METHOD FOR IMPROVING AEROSTAT ENDURANCE USING MICROPROCESSOR CONTROLLED FEEDTUBE (PATENT APPLIED)

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Abstract — Enhanced 24X7 surveillance has become a pre-dominant part of country's strength and the same been realized using various platforms. Presently platforms such as satellites, Unmanned Aerial Vehicles(UAV), aircrafts, Lighter Than Air(LTA) vehicles are used widely to gain intelligence gathering and monitoring applications. Of all the above platforms the LTA vehicles are gaining much importance due to its inherent stability characteristics, loitering capabilities with minimum disturbance and 24X7 continuous monitoring capability. The aerostat vehicle is one of its kind in LTA widely used for surveillance and monitoring. The aerostat is a balloon filled with LTA gas(helium/hydrogen) to provide the lift and it is moored to the ground using an electromechanical cable called tether. The aerostat works on the principle of buoyancy and the lift is generated by helium/hydrogen gas lighter than air. One of the important aspects considered during design of LTA based surveillance system is its endurance. The endurance primarily de-pends on its gas leakage, impurities adding up to lift gas due to various phenomenon. The buoyancy/lift force produced is directly proportional to the purity of lift gas, volume of gas and aerostatic parameters based on environmental conditions. For a given altitude, considering the environmental perturbations as constant the buoyancy force or lift produced depends on the volume of gas present. The lifting gas leaks due to fabric porosity and joints present in the system. The gas need to be re-furbished periodically to regain the calculated buoyancy force. For re-filling the system needs to be lowered which is a major drawback. Also the surveillance gets interrupted during lower-ing. To overcome this drawback refilling of gas need to be online. Tethers can be broadly classified based on the applications with reference to its features supported. A simple-tether available worldwide supports strength, electrical and optical coupling feature. Recently researchers are working on a concept-tether where a feedtube is embedded to support online top of lift gas. The novel-tether presented in this paper is a novel design of feedtube tether which supports more features than simple-tether and concept-tethers. In this paper the conceptual design and architecture of noveltether, advantages and disadvantages, its interface with a microprocessor controlled valves and various operational modes are explained. A micro algorithm and flowchart depicting various mission scenarios and valve control is also discussed. By adopting the novel-tether technology the aerostat system endurance can be improved from weeks to months. This is discussed in detail in the sections below.

Keywords — Aerostat, Feedtube, Microprocessor, Helium, Endurance, Surveillance and monitoring

I. INTRODUCTION

Intelligence and surveillance plays a major role in building countries defense. In the recent past there are several platforms deployed for surveillance. Of all the surveillance systems aerial platform is gaining much importance due to its inherent advantages of better visibility covered for a particular field of view. There are many platforms deployed for aerial surveillance and intelligence gathering. Some of the proven platforms are satellites, aircrafts, UAVs, helicopters, aerostats and airships of low medium and high altitudes using LTA technology. Of all the above mentioned platforms, LTA systems proves to be more advantages due to its inherent property of being stationary in air for long duration. This property increases the capability of surveillance by multiple folds. The present system other than LTA can be used for surveillance for a limited amount of time or to a specific FOV with certain time limits. But with LTA aerostat system 24X7 continuous surveillance can be achieved. Aerostat is one among the LTA system which uses lighter than air gas(like helium or hydrogen) and floats in the air using its buoyancy. The aerostat is a balloon filled with helium/hydrogen gas and moored to the ground using an electromechanical cable called tether. It can be raised or lowered by a electro mechanical winch system. The aerostat platform can be used for surveillance and intelligence gathering by mounting Electro Optic (EO) sensor, Communication Intelligence (COMINT) and Electronic Intelligence(ELINT) payloads. The endurance of the system is defined as the number of days the aerostat is airborne before topping up of gas. The balloon is made of special fabric. The fabric porosity, diurnal temperature variation can increase the gas loss or decreases its purity. This reduces the payload capacity and the system to be topped up for the amount of gas loss. For topping up the balloon has to be lowered using the winch system which requires considerable amount of manpower effort, time and cost. There is a strong requirement from users to increase the endurance of the system from days to months. Present aerostat systems having a volume of 2500cubic meter with a deployment altitude of upto 1km can have an endurance of approximately 10 days based on payload, fabric material and deployment fields. The author introduces a novel concept of increasing the endurance of the system to multiple fold and the same is explained in detail in this paper.

II. BASICS OF GAS PERMEABILITY IN FABRIC

The aerostat is subjected to ultraviolet rays, drastic fluctuations in temperature over day and night, etc due to its prolonged flying condition. Also due to permeability the gas inside the fabric permeates out through the fabric skin and outside air from atmosphere permeates inside the fabric reducing the helium purity. This phenomenon reduces the aerostat buoyancy force and reduces its payload carrying capacity. Also this affects directly the endurance of the system. The aerostat need to be brought down and to be topped up for the loses. However the purity cannot be regained until the gas is recycled. To arrive at a function for the helium gas loss let us consider the equation below,

$$F \ \alpha \ (p_1 - p_2) \ldots\ldots\ldots\ldots\ldots\ldots(eq1)$$

F – Flux through a surface either measured as volume of gas percolated /diffuse[3] through unit surface area in unit time or as moles of gas percolated from unit surface area in unit time.

$p_1 - p_2$ - Partial pressure of the gas across the polymer membrane.

The rate of change of number of moles in the hull/ballonet is directly proportional to the difference in the partial pressure of the respective gases as in eq.2

$$\frac{dn}{dt} \ \alpha \ (p_1 - p_2) \ldots\ldots\ldots\ldots\ldots\ldots(eq2)$$

Ideal gas equation is given as

$$PV = nRT \ldots\ldots\ldots\ldots\ldots\ldots(eq3)$$

P – Pressure of the gas
V – Volume of the gas
n – Number of moles
T – Temperature of the gas
R – Gas constant

Using the ideal gas equation the eq.2 can be expressed as below in eq.4

$$\frac{dn}{dt} \ \alpha \ A\left(\frac{n_1RT}{V_1} - \frac{n_2RT}{V_2}\right) \ldots\ldots\ldots\ldots\ldots\ldots(eq4)$$

v1 & v2 are volume of gas in helium and atmosphere region

Due to permeability of fabric the helium molecules get transmitted to atmosphere and air molecules enter helium region which makes the gas impure. The rate of change of moles of helium is derived from eq 4 using superposition principle and net change in moles of helium is equal to the addition of moles transmitted out to the other region of balloon and moles transmitted out to atmosphere as given in eq5.

$$\frac{dn_{He_{H,t}}}{dt} = k_{He2} A_2 \left(\frac{n_{He_{b,t}}RT}{V_2} - \frac{n_{He_{H,t}}RT}{V_1}\right) + k_{He1} A_1 \left(0 - \frac{n_{He_{H,t}}RT}{V_1}\right) \ldots\ldots\ldots\ldots\ldots\ldots(eq5)$$

Using the derived equations with supporting functions the rate of helium loss can be determined which forms the basis
for calculating the endurance of the aerostat system. As per test results for an axis symmetric shape with a initial gas(helium) purity of 99% maintained at a gauge pressure of 800Pa having an inflation ratio of 0.9 the percentage purity of helium reduces to 96.4% in a span of 180 days.

III. AEROSTAT SURVELLIANCE PLATFORM

Aerostat works on the principle of buoyancy using(lighter than air) and lift is provided by the gas mainly by helium/hydrogen. Globally most of the aerostat system uses helium as lift gas due to its inherent safety against fire. The aerostat platform is shown in Fig 1.

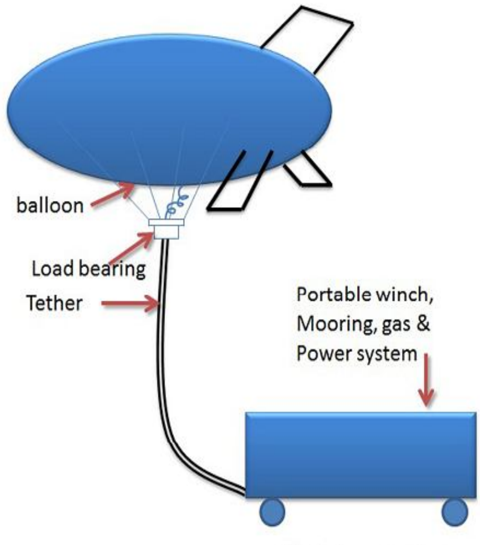


Fig 1: Aerostat System

The aerostat platform has the following subsystem such as balloon made of laminated fabric or fabric with low porosity, an optical and electro coupler with a strength bearing membrane for transmitting the power & data from the airborne end to ground vice versa, mooring system for raising and lowering the balloon and to support the balloon platform, tether cable a medium for carrying power and data to airborne system, gas management system for gas refurbishment, power management system for supplying power to the airborne and the winch mooring system, control and monitoring system for monitoring the critical and non-critical parameters and payloads. The sub-systems are explained below in brief.

3.1 Balloon subsystem:

The balloon subsystem is made out of fabric which is less porous to the helium/hydrogen gas. The size and shape of the balloon system is determined based on operational altitudes, payloads weights and environmental conditions. The stability of the system primarily depends on its size and shape. On the periphery of the balloon deflation valve for emergency condition, inflation valve for filling the gas, strobe lights, truss for mounting payloads and electronic systems. The balloon is filled with helium or hydrogen gas.

The balloon platform is raised or lowered by using winch and mooring system. Attitude and heading reference system sensors are used for balloon stability maintenance during flying condition. This balloon system use active ballonet or passive ballonet technology to maintain stability, shape and other critical properties during flying condition. The balloon is supported by confluence lines fixed to the load bearing joint.

The other end of the joint holds the tether assembly. The balloon is raised or lowered by a motorized winch system. Payloads such as EO sensor, ELINT/COMINT are mounted using truss in the balloon. The payloads can be used for sur veillance/imaging and intelligence gathering.

During aerostat normal operation the balloon is moored in the platform for gas refurbation. The balloon is raised to a sufficient altitude required for surveillance. Due to porosity and diurnal temperature variation the gas in the balloon starts leaking. Also due to air mixing the purity of the gas reduces.

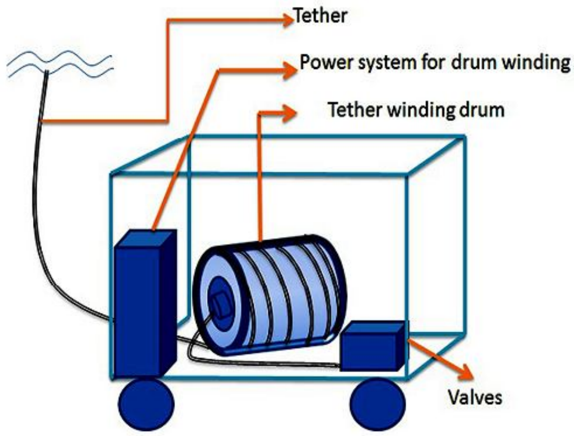
The overall payload capacity drops due to the above scenario.

To compensate the loss of helium, refurbishment of helium is done within a time period typically ranging from days to weeks based on the aerostat system and environmental parameters.

3.2 Tether:

A tether is a electromechanical cable which holds the balloon at the airborne end and connected to winch and mooring system at the ground end. The tether provides primarily strength for holding the balloon. Also it establishes electrical/ connectivity between airborne and ground end. The tether is made up of multiple layers. The innermost core is made of optic fiber for communication above electrical conductors for payload and other subsystems power above that there is a strength bearing membrane and above sheath for lightening protection system for discharging the lightning current to ground. The ground end of the tether is connected to a winch drum through a rotary joint as shown in fig 2.

Fig 2: Winch & Mooring inner view



This joint isolates the rotational motion between the drum and tether without breaking the electrical and optical onnectivity. At the airborne end the tether terminates at the strength bearing joint. The electrical and optical wires are pulled out from the joint to provide connection to the actual systems fitted in the balloon. As discussed for topping up of helium/hydrogen gas the balloon needs to be lowered by using the winch and mooring system. This needs considerable amount of time, effort and cost. Also apart from the above cons, the disadvantage is due to non-availability of surveillance during these periods. In this paper a novel-tether is designed and explained where the balloon need no lowering for topping up. The online top-up methodology is followed during the design approach and novel-tether has been architected to support the online top-up methodology with microprocessor control. The conceptual construction of tether and its working methodology is explained briefly in the sub-sequent sections of this paper. Since winch and mooring, power management system, gas management system is out of scope of this paper it is not discussed in detail.

4. Design of Novel Tether:

As explained in the previous topics for any surveillance system availability for 24X7 and its endurance is an important factor considered by users for its selection. Of all the methods of improving endurance the on-line topup method finds best suitable for its inherent advantages as below.

Stability and control
Less manpower support required for its maintenance
No system downtime, 24X7 surveillance[8] available
Low operational cost

Some of the disadvantages are

Tether design becomes more complex
Overall weight of tether per meter increases and may reduce some of its payload capacity for the same specifications.

There are patents available online depicts about the online topping and its methodology of operation and its construction. In this paper novel tether explained has feedtube with microprocessor based controlled valves for its upward/downward gas flow. Also this construction is unique from others which are available due to its fact that the gas flow direction is bidirectional and its supports during exigency/emergency operation during its blockages. Fig.3 below depicts novel feedtube tether architecture and its connectivity.

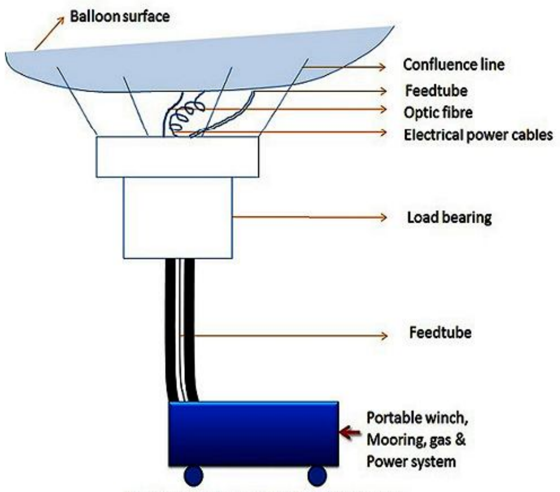


Fig 3 Novel Feedtube tether attachments

The novel feedtube tether consist of an outer cloth jacket to protect it from the environmental effects, below a lightning protection braid for providing the path to the discharge current, below electrical conductors for providing power to the airborne monitoring and payload systems, below optic fibers used for data communication and below the innermost core has the feedtube for upward and downward flow of gas. As per study and by practical experiments in an aerostat system of size 2500cum with a differential pressure of 3mbar flying at an altitude of 1.2kms the gas loss is estimated to be 100cum per day. The feedtube diameter can be calculated based on the gas loss with refilling duration requirement at a specific pressure. The novelty in this feedtube tether other than the available tether is its capability to interchange its upward or downward gas flow motion with microprocessor controlled valves.

4.1 Tether constructions currently available:

4.1.1 Simple tether:

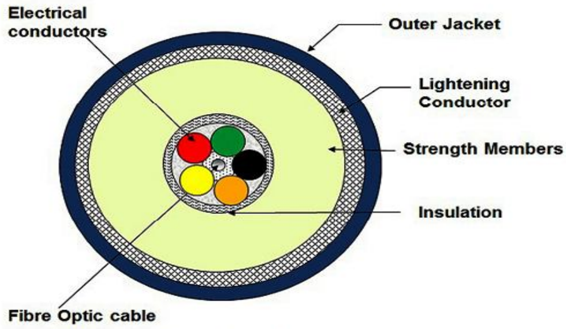


Fig 4: construction of simple tether

Fig 4 explains the construction of simple tether used in aerostat system. As described earlier the tether is composed of multi-functional elements. The outermost layer made of special fabric for protection against environmental factors, the layer below is a lighting braid for discharging the excess current created due to lighting effects, underneath layer is a strength bearing membrane, electrical conductors and optical fibers.

4.1.2 Concept-tether available worldwide:

In concept-tether in addition to all the layers for their respective functionality, a bifurcated feedtube runs through the complete length for online to pup of gas. This is shown in Fig 5 .

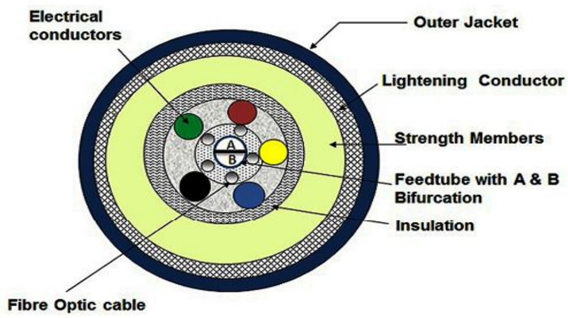


Fig 5: construction of concept tether

4.1.3 Novel-tether construction:

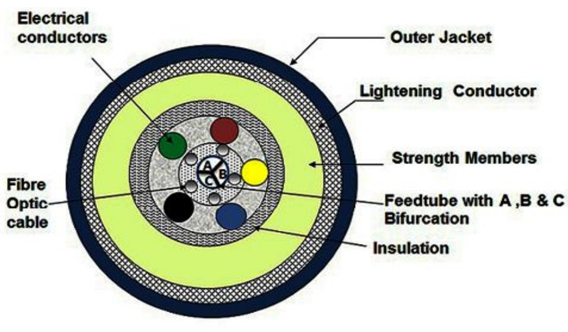


Fig 6: Construction of novel tether

In novel tether the feedtube is bifurcated into three parts as shown in Fig 6. Each of the bifurcation can function for upward gas flow or downward gas flow. Based on the mission requirement the bifurcations can be programmed for upward gas flow or downward using a microprocessor controlled valves. This feature supports and extends the endurance during emergency conditions. During flight experiments a mission is considered as emergency mode when gas flow either upward or downward gets disrupted due to a block in feedtube. Also the helium can be recycled which improves the system endurance. The below section explains more about the novel feedtube architecture, microprocessor interface, algorithm for valve positions based on functional requirement and flowchart depicting the overall system configuration in detail.

4.2 Construction of novel feedtube and its interface with microprocessor:

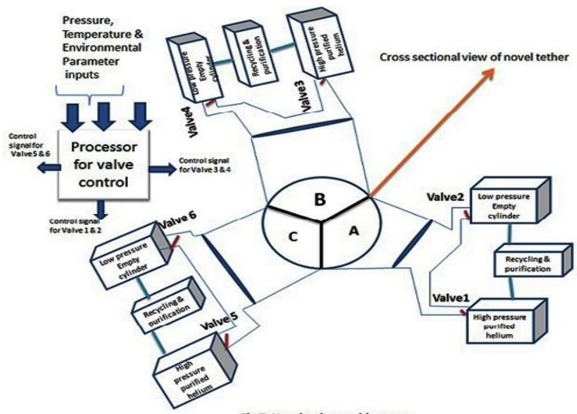


Fig 7: Novel tether architecture

-partments for upward/downward gas flow as shown in Fig 7. The cross section A, B, C is connected to high pressure tank which includes recycling and purification of gas at the groundend through a microprocessor system. The feedtube is embedded at the innermost layer in the tether and at the groundend the tether is wounded in a winch drum. From the winch drum the tether passes through tension balance system and it terminates over the gas management system. The gas management system has 3 compartments for its overall recycling purification and pressurizing. At the groundend the rotation of the tether is decoupled by a rotary joint. Each bifurcation in feedtube has separate inlet and outlet valve.

The inlet valve(v2,v4,v6 in fig 7) placed in low pressure empty cylinder controls the direction of flow of gas from airborne to groundend and outlet valve(v1,v3,v5 in fig 7) placed in high pressure purified helium tank controls gas flow from groundend to airborne end. Also in all the bifurcation the gas flow is bidirectional. The direction of flow of gas from ground to airborne and vice versa is controlled by set of conditions based on mission requirement. The table 1 below explains the various modes of control requirement and its corresponding valve positions to match the same. The functional requirements are classified as normal inflation, normal deflation, online topup during normal condition, emergency conditions, and during feedtube block. During normal inflation and deflation all the bifurcations A, B & C behaves as unidirectional upward and downward respectively. During normal working condition when the balloon is airborne among the three bifurcations, one compartment performs for upward flow functionality, one compartment performs for downward flow and one compartment is kept redundant, if 33% flow rate is required for refilling. This is done to replace the continuous loss of gas and helium recycling. Based on refilling rate requirement 1 or 2 compartment can be programmed for upward gas flow. Accordingly the valves are programmed and kept in open or closed position allowing the gas to flow. The low pressure cylinder always takes the gas in for purification from airborne and high pressure cylinder releases the gas after purification to airborne. During emergency mode if any of the bifurcation is blocked redundant compartment can be used. Blockage scenarios with cases are explained in table 1 for more clarity.

Table 1: Functional requirement Vs valve programming table

S. No	Functional Requirement	Valves						Remarks
		A		B		C		
		V1	V2	V3	V4	V5	V6	
1)	Normal operation no Change in pressure, Temperature & Environmental conditions detected	No Change in valve position						Feed tube behaves as programmed bidirectional.
2)	Pressure Temperature & Environmental values matches emergency deflation	Closed	Open	Closed	Open	Closed	Open	Feed tube behaves fully 100% downward flow.
3)	Pressure, Temperature & Environmental values matches with filling of helium(100% flow in)	Open	Closed	Open	Closed	Open	Closed	Feed tube behaves fully 100% upward flow
	a) For flow rate 33% requirement	Open	Closed	Closed	Open	Closed	Closed	Feed tube behaves bidirectional 33% upward flow.

	b) For flow rate 66% requirement	Open	Closed	Open	Closed	Closed	Open	Feed tube behaves bidirectional 66% upward flow
	c) For flow rate 100% requirement	Open	Closed	Open	Closed	Open	Closed	Feed tube behaves fully unidirectional 100% upward flow
4)	Pressure, Temperature & Environmental values matches with initial inflation	Open	Closed	Open	Closed	Open	Closed	Feed tube behaves fully unidirectional 100% upward flow
5)	Pressure, Temperature & Environmental values matches with any block in any of the bifurcation in feed tube 1) If 'A' is blocked during upward flow program 'C' to behave as upward.	Closed	Closed	Closed	Open	Open	Closed	The 'C' bifurcation in feed tube function as inlet.
	2) if 'B' is blocked during downward flow program 'C' to behave as downward	Open	Closed	Closed	Closed	Closed	Open	The 'C' bifurcation in feed tube function as outlet
6)	Pressure, Temperature & Environmental value matches with normal deflation requirement	Closed	Open	Closed	Open	Closed	Open	The feed tube fully behaves 100% downward flow

The unique model of this novel feedtube is that the gas flow direction in any of the valve can be bidirectional.

4.3 Microcode structure:

The novel feedtube tether function is controlled by a microcomputer. The microcomputer is interfl;aced with the environmental and system monitoring parameters sensor. The controller receives the pressure, temperature and other environmental conditions for its process calculation. Based on the conditions the microcode/control processor executes the algorithm and switches the valve for its required functions. As described the program initializes with data received from the sensors and matches with the pre-defined conditions as per the mission procedures. If any of the conditions matches accordingly it executes the driver algorithm to open or close the valve switches. A detailed flowchart in table 2 depicting the various conditions and required functionality is given for more clarity.

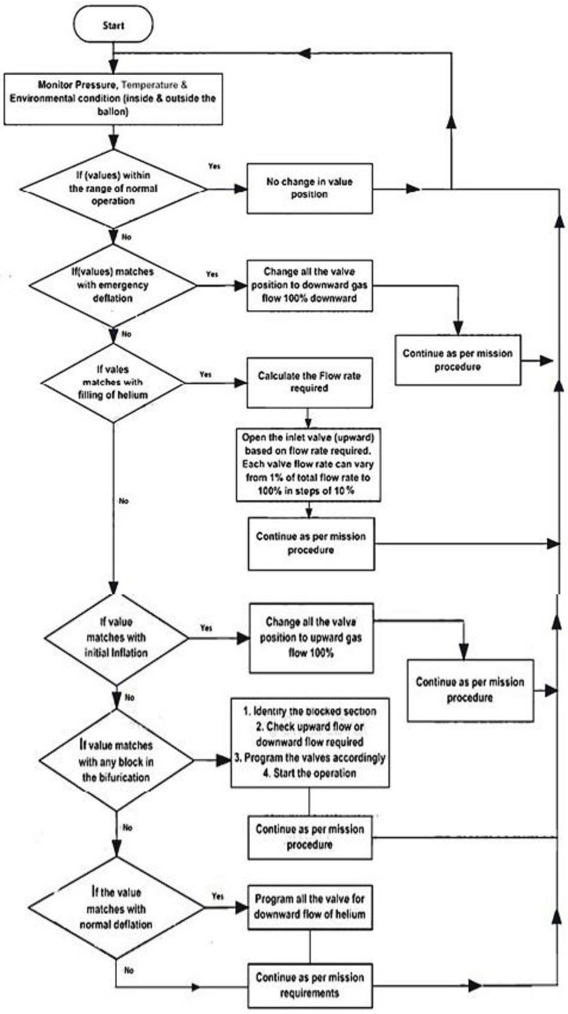


Table 2: Flowchart: Microcode algorithm structure

CONCLUSIONS AND APPLICATIONS:

As discussed earlier 24X7 surveillance and monitoring has become a predominant requirement in any field. The payload [10] requirement can range from the field of defense to civilian and commercial requirements. None of the present surveillance system except LTA system can establish continuous surveillance. Even with present LTA aerostat systems with a limited period of operation the system needs refurbation of gas for its operation. The novel helium feedtube tether overcomes the above disadvantage and paves way for almost infinite endurance. Also present system during transportation and reinstallation the helium/hydrogen gas is released without bringing back for storage. This leads to high operational cost. This drawback can be avoided by helium recycling and storage during deflations which can be a cost effective solution.

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