Analysis of the Flexibility of a Soft Hinge with a Floating Power Connection

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Abstract. Providing high safety standard for aerospace field is one of the most important issues that designers and engineers must face [1, 2]. It is especially important for life support systems, which consist of a set of tools used to ensure human safety while maintaining high performance. However, human needs to have a stable and comfortable environment inside the suit, as well as an appropriate suitable and high-tech equipment. One of the most important problems in the development of perspective spacesuits (extravehicular and rescue) is the flexibility of the legs and especially the arms of the spacesuit. Ideally, the level of flexibility of the spacesuit should correspond to the level of flexibility of a person in ordinary clothes. This paper presents an analysis of the flexibility of a soft hinge with a floating force connection, guaranteeing the mechanical flexibility of the soft hinge elements. The advantages and disadvantages of corrugated joints are discussed. Conclusions have been drawn on the relevance of using soft joints with a floating force connection in space suits, especially in gloves. This paper discusses requirement analysis on the materials used for gloves manufacturing as well as test procedures used to the requirements control.

1. Introduction

Space is a highly dynamic environment that poses many hazards [3]. This must be taken into account while choosing components and materials for the exoskeleton. The glove and the suit in general should guarantee a certain safety level through a multilayer system. Despite the protective layers, some problems related to the space environment still persist such as cosmic dust, electromagnetic interferences, high temperature variations, micro-meteoroids.

The number of manned space flights has increased significantly in the last decades and manual operations are playing a key role in extravehicular activities. Gloves, used by astronauts during EVA, are protecting their hands from the hazardous conditions of space. Since hands are the major tool that astronauts have, the glove is one of the most important parts of the spacesuit [4]. However, due to its pressurization and to the spacesuit multilayer structure, the glove is also a very critical part. Hand fatigue, dexterity reduction of the fingers and consequently decreasing of working hours are some of the most common arising problems [5-8].

Different solutions are offered, on one side the development of novel gloves with lower stiffness, on the other the design of exoskeletons or other external devices to overcome the stiffness [9-11].
2. Overview

Different gloves designs have been developed aiming to improve comfort and convenience. Gloves of the spacesuit are made from multiple layers of insulating materials and durable fabrics for sealing, insulation and protection, but they are flexible enough so the astronauts could handle tools and perform tasks using their fingers.

Easing of use of the gloves and minimizing of the movement resistance of the fingers while maintaining all of its protective properties is a critical parameter of work outside the spacecraft or station, especially if we are talking about using tools.

Depending on the type of gloves, the number of special loops in the turns, bending and the degree of freedom may be different. The increasing of the volume and complexity of work in outer space, changes requirements on flexibility of the fingers and joints of the hand’s suits on a hinge level. As a solution a combination of fabrics used to produce the gloves is changing, improving their tactile characteristics.

The glove of the spacesuit (the COP) has the following layers: a protective shell, power shell, thermal and meteorite protection (TMZ). The protective sheath is made of polyurethane. This is the inner layer of the gloves, providing a sealing and inflating of gas of the COP. The next layer is the power shell that maintains the shape of gloves when boost and equipping the movable hinges and adjusting elements. The outer layer of the glove TMZ provides protection from damage. Inside the glove is a rough cloth: the fingers are made of special rubber, also there is a metal insert protecting from wrist fractures broken.

3. Design solutions

The designs of the currently used hinges [12, 13] provide bending in one plane, rotation, as well as rotation and bending in one and two planes (combined hinges). It is needed to imitate all the movements as accurate as possible. The human palm in normal position has a concave surface appeared between the heel of the hand and fingers. It appears due to its physiological structure, especially in a bent position as it is possible to bent fingers only to one side. To ensure the necessary concavity (at pressure), a rigid frame is mounted on the palm of the glove. There is closed with a tape on the back side, which serves to regulate the dimensions. Hinges are installed in the places corresponding to the location of the joints. As a result, satisfactory flexibility can be obtained without overpressure and in the presence of an internal overpressure in a spacesuit. The design of the gloves is aimed at the natural position of the relaxed hand, which helps to reduce fatigue.

The design of the joints in the spacesuits depends on the nature of the performed movement. First of all, elements of the hinges should have a minimum limitation on human movement, and they should be as simple as possible in their design. They should fit well too. Longitudinal forces must be transferred to the force elements located in the neutral surface or plane of the hinge. Otherwise it is not possible to move at an overpressure of more than 10 kPa. This is due to the fact that the effort required to deform the shell, exceeds the physical capabilities of human; bending aerobalok forms deep folds, damaging the body. Soft hinges allow only bending of parts of the body and reduce the effort required for bending. They allow the movement of parts of the body in the required range of angles, and it is achieved by constructive features. The main idea is in the longitudinal forces transmission to the force elements located in the neutral surface or plane of the hinge.
Figure 1. Joint scheme with a movable longitudinal tie: 1 - bumps; 2 - circular tape; 3 - movable longitudinal binder.

Figure 1 shows a soft corrugated hinge, characterized in that the longitudinal tie of the hinge is made movable, and connected to transverse circular bands through elastic elements made, for example, of rubber.

Figure 2. Joint scheme with a movable longitudinal tie.

The currently used corrugated hinges in the glove do not have the proper flexibility. Ideally, the soft hinge of the spacesuit should not resist the movements of the astronaut's limbs. A soft corrugated hinge is proposed as a good practical solution. It is characterized by the longitudinal hinge of the hinge which is movable (Fig. 2) connected to transverse circular ribbons through elastic elements made, for example, of rubber.

Adverse factors that pose a danger to crew members are the result of the influence of the space environment, the influence of flight dynamics, isolation, limited reserves of means of providing vital functions, the possibility of the appearance and formation of toxic substances, and more.

4. Requirement management
The materials used for spacesuits have very high requirements [1, 17, 18]. Adverse factors that pose a danger to crew members are the result of the influence of the space environment, the influence of flight dynamics, isolation, and limited reserves of means of providing vital functions, the possibility of the appearance and formation of toxic substances, and more. All materials intended for the manufacture to produce a high-altitude spacesuit must have the most detailed specifications. Special importance is given to the non-deforming properties of the fabric. Fabrics such as Nylon, Nomex, Pandex, Urethane Nylon, Dacron, Neoprene Nylon, Mylar, Gortex, Kevlar and other materials, in
addition to the normal test program, must undergo repeated bending and aging tests. The material should not only fully withstand all possible pressure differences, but also should not be rubbed when the astronaut walks, when kneeling, and not tear when accidentally dropped; at the same time, the spacesuit should allow the astronaut to do useful work and conduct experiments both inside the spacecraft and on the outer surface. The material should also be tested for resistance to high and low temperatures (from +150 to -60 degrees Celsius).

In addition, these materials have special requirements. Rubber and rubber fabrics are especially carefully tested for frost resistance, exposure to oxygen and ozone. In special experimental studies it was shown [14] that when exposed to rubber products, ozone in concentrations of 0.0012-0.01 for several hours did not become brittle, completely lost their elasticity and resilience.

5. Conclusions
Deformability and strong formability of the soft shell, creates difficulties in production and influences on requirements.

This study analyzed approaches to the spacesuit gloves design and its requirement management. The most important procedures used for preliminary acceptability were listed.

For fabric materials, it is necessary to simulate a soft shell with a two-dimensional continuous medium, since in the third dimension the structure of the material does not allow it to be considered continuous in thickness [15, 16, 20].

It is recommended to use a special power tape passing through the anatomical structure of the hand, the use of rubberized material, and the use of corrugated joints.

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