International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 11 | Nov 2020 www.irjet.net p-ISSN: 2395-0072

Review Paper on Spacesuit Integrated Carbon Nanotube Dust Removal System

Aditya Bhartia

B.Tech. Student, School of Electrical Engineering, Vellore Institute of Technology, Vellore, Tamil Nadu, India

***

Abstract - *Mankind is taking breath-taking strides towards space travel and it is important to ensure the safety of the astronauts who embark upon this journey. In the future Lunar, Mars and Asteroid missions, dust mitigation from spacesuits will play a very vital role to ensuring the safety and success of these missions. Scientists at University of North Dakota (UND) constructed a scaled prototype of the knee portion of a planetary spacesuit utilizing specifics of the NDX-2 lunar spacesuit and conducted this study. The outer layer is embedded with the CNT dust removal system and tested under various conditions to review efficiency and effectiveness. This study was conducted as a continuation to the previous study where they used Carbon Nanotube (CNT) yarns as electrode wires embedded into coupons made of spacesuit material.*

Key Words: Dust Mitigation, Spacesuit, Carbon Nanotubes (CNTs), Ultraviolet (UV) Radiation, NDX-2 Lunar Spacesuit, Electrode Insulation, Extravehicular Activity (EVA), Alternating Current (AC), Relative Humidity (RH)

1. INTRODUCTION

The Research Paper basically talks about a method of dust mitigation for spacesuits, which is extremely critical for future Lunar missions, as well as other planetary exploration missions such as Mars, and Asteroid missions. Lunar dust posed to be a huge problem during the Apollo Missions, abrading spacesuits, clogging seals and other critical equipment. Lunar dust is electrostatically charged due to Solar Winds and UV Radiation. For future long-term Lunar and other missions, it is critical that this dust does not stick to the spacesuits as it can prove to be lethal when inhaled in larger quantities and also cause faults in machines.

University of North Dakota constructed a scaled prototype utilizing specifics of the NDX-2 Lunar Spacesuit. The outer layer of this spacesuit is embedded with the CNT Dust Removal System and tested under various conditions. For a prototype, the part below and including the knee was chosen, as it is one of the most complex parts of the body and when walking on the planet or the Moon, dust would first settle on the knee joint, then anywhere else.

2. CONSTRUCTION

Construction involves fabrication of the outer layer, placement of CNT Fibre Electrodes and pressure bladder which is separately constructed with aluminium ends to facilitate pressurizing of the module. The outer layer is build using pleats and gores, where the pleats are patches of clothes, mostly in excess (for facilitating contraction and elongation in case of knee bends), and the gores are at the backside of the feet, for rolling purposes. CNT fibres were embedded circumferentially and parallelly throughout the front section of the knees, for ease of manufacturing, terminating electrodes circumferentially instead of longitudinally (as plates expand longitudinally), and also keeping in mind the direction of electrical fields. The outer layer is attached to the pressure-restraint assembly using Velcro around the circumference of the top and bottom of the outer layer. More than 50 test cases, or pressurization cycles were done, at 2.5-3 psi. Flight Operating Pressure for spacesuits have been observed to be around 3.5-4.3 psi, but it was noticed that 3 psi and 4.3 psi do not differ substantially.

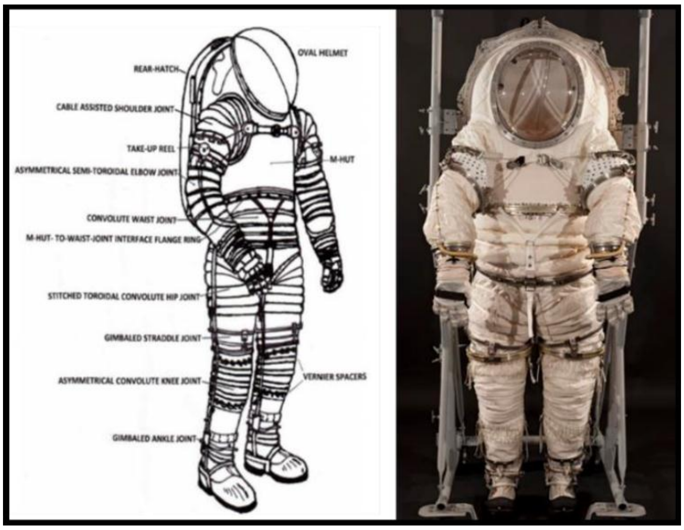

Fig -1: NDX—2 Lunar Spacesuit prototype build at UND

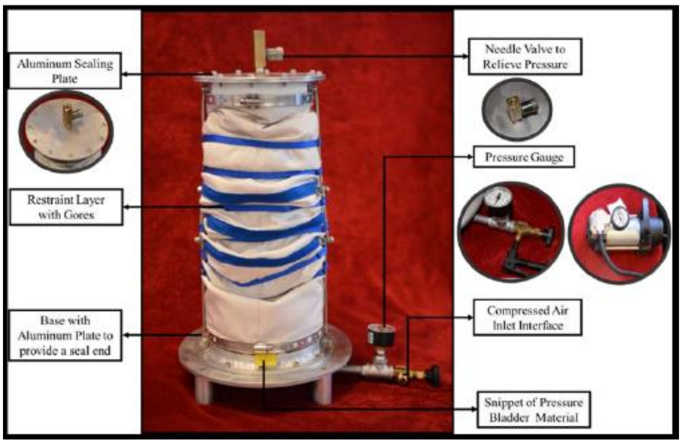

Fig -2: Pressure bladder-restraint assembly prototype

3. MECHANISM, TESTING AND EVALUATION

The Spacesuit Integrated Carbon Nanotube Dust Ejection/Removal (SPIcDER) system on the scaled knee-joint section was evaluated at three bend (flex) angles of the knee under two specific dust depositing conditions (similar to the ones implemented on the previously performed Coupon test by NASA). Two testing conditions were taken into account, namely, Dynamic Drop test, and Static test. 3 runs per angle were performed for each dust loading to identify repeatable performance.

Dust of grain sizes 50-75 μm and 10-50 μm was utilized, at room temp. 23°-25°C and RH 39-41%. For Dynamic test, the system was activated prior to dust drop, vice-versa for static test. Dust was angularly dropped on the prototype as during an EVA on the Moon, dust can be deposited or dropped from any angle. Bend Angles were set to 15°, 30° and 45°. Normally, astronauts can bend their feet from 10°-60°.

Fig – 3: Dust Loading Method

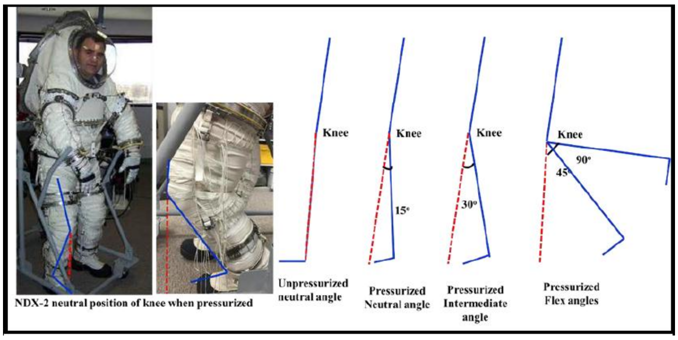

Fig – 4: Angles of knee tested for dust cleaning performance of SPIcDER

Testing involved Breakdown Voltage Calibration and Test Runs. Voltage at which arcing occurs (Breakdown Voltage) for each bend angle was noted. After this, actual experiments were conducted for both the tests at all the bend angles, 200V below the breakdown voltage.

Data was collected using microscopic and macroscopic imaging and videography. Qualitative and quantitative analysis were used to assess the performance of the SPIcDER system and its scalability with data obtained. The dust cleaning capability was evaluated using 1) Visual inspection via the videography data and images collected document observable dust cleaning capability for the qualitative aspect of the analysis 2) For the quantitative aspect, images were analyzed using ImageJ software to estimate the overall percentage of dust covering the ortho-fabric before and after cleaning.

The voltage where the surrounding medium breakdowns due to electric discharge is dependent on the electrode configuration and the surrounding gas pressure. Knee angle impacts the fabric layout, i.e., the fabric might have wrinkles/folds/creases when unpressurized and when the knee is in a neutral position (no flex angle) when pressurized. These creases in the fabric may stretch/smooth out when the knee is in a flexed position. There might be areas where the fabric creases so much that the electrodes potentially overlap impacting the value of breakdown voltage. When pressurized, the pressure inside the module helps the outer layer fabric to bubble outward allowing smoothing out of the creases. This brings about a change in the breakdown and threshold voltage for each test condition. The threshold and operating voltages on the knee prototype were ~100-150V lower than the coupon experiments. This is due to creases and overlapping of electrodes. Also, due to manual embedding of the electrode fibers, the electrode spacing was irregular, causing irregularity of electric field. Also, since the fibers were uninsulated, there could have been many micron sized CNT fibers sticking out causing this anomaly.

The 50-75 μm showed extreme clearance, but 10-50 μm dust did not clear well, as grain of that size are extremely cohesive. However, one critical observation during the 10-50 μm dust was that, even if clusters of dust adhered to the fabric, when additional dust, was dynamically dropped over these areas already contaminated with dust, the new dust picked up the already adhered dust and visibly cleared the area.

Fig – 5: Pressurized module. Arrows point to creases in the knee area

4. RESULTS OF THE STUDY

For the 50-75 µm dust loading, results show that the system can clear most of the dust dropped over the knee and the percentage of dust covering the knee post cleaning is within 5% of the fabric area at all angles. The difference in performance of the system was minor between all three angles tested, with the 15° position having the highest (5.4%) percentage of area covered by dust. Compared to the coupon tests, the knee experiments show an increase of approximately 2.5% in the dust remaining on the fabric. This could be due to 50-100V lower operating voltage.

For the 50-75 µm dust, the dust clearing performance (% of dust removed) is between 92-95%. The system could clear most of the statically adhered dust. Comparing the coupon test and the knee results, the percentage dust covering the coupons was 2.3 % compared to the 4.9-7% in the current experiments. This difference can be attributed to the difference in operating voltages for the coupons (0o), 15o and 45° knees angles, were 1000 V, 900-945 V and 970 V respectively. This ~50-100 V decrease in the operating voltage has a direct impact on the electric field intensity; lower electric field compared to relatively higher electric field value on the coupon tests (0°).

The overall performance of the SPIcDER system on the scaled unit shows promising results to further this technology for spacesuit dust cleaning operations. Based on the data, the overall efficiency of the system for a pressurized module is estimated to be in the range 75-96% depending on particle size and knee angle. The worst-case scenarios are when the knee angle is 15°, with the 10-50 µm grain size particles, due to reason stated above. However, the performance significantly improved when fresh dust was dropped over the areas where dust already adhered.

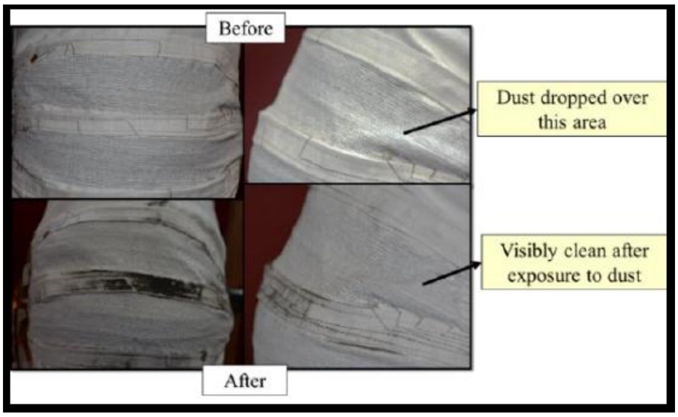

Fig - 6: Images of the knee for dynamic dust cleaning operations

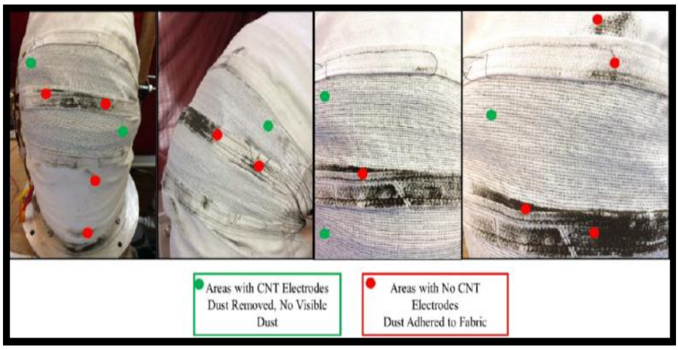

Fig - 7: No visible dust within electrode area; dust collected in areas with no electrodes

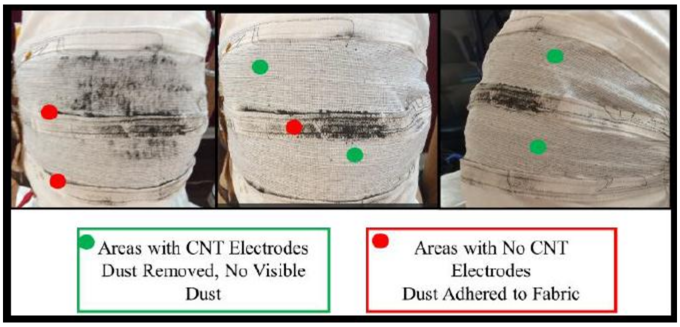

Fig - 8: Before and after comparison of the static dust locating cleaning operations

5. CONCLUSION AND IMPROVEMENTS

The novel concept and design proposed by the researchers at the University of North Dakota had surprising results and the technology applied, can be used in the upcoming Lunar and Mars missions post some more extensive research. As a continuation to this study, the feasibility of scaling this CNT dust removal system on larger portions of spacesuit is currently under investigation. The investigations and performance observed in the study of the prototype discerns that the dust mitigation process used can be extrapolated feasibly over larger sections of a spacesuit. From the data analysed, the percentage of area covered by dust after implementing the SPIcDER system is in the range 4-16%, below the set requirement of the research of 25%. The dust removing capability of the SPIcDER system is estimated to be between 75-96% on the scaled prototype depending on the dust exposure conditions for lunar dust simulant with particle sizes between 10-75 μm at three different knee angles.

Limitations where lower performance was observed is due to the fabric being covered by several layers of dust, especially the cohesive 10-50 μm grain size. However, this was shown to overcome when dust contaminated fabric was exposed to fresh dust. The results will improve if the future tests utilize congruous mixture of small and large particle size distributions replicating lunar dust particle size distribution.

Some suggestions proposed by the researchers are electrode insulation, consistent electrode spacing and terminal connections. Electrode insulation ensures that the CNT filaments are aligned and the wires are not frayed, which in turn leads to higher breakdown and operating voltages. Alignment and spacing of the CNT fibres can be improved by automating the weaving process, thus ensuring that the thickness of fibres and distance between them is uniform. Inclusion of CNT fibres in the suit fabric using automation in the early stages of manufacturing would be optimal. This would help maintain a consistent breakdown voltage, thus ensuring consistent operating voltages. This would also improve the electric field force and better the efficiency of the system against smaller grain sizes. To avoid overlap of three-phase terminals, a set of terminals can be connected inside the fabric.

Further research on the electrode arrangement patterns, for instance, spiral pattern within the gores, or longitudinal pattern would help reduce the accumulation of dust on the edges of gores. Alternatives to design the gores to reduce pockets and fabric overlaps should also be explored to mitigate this issue. Implementation of a duty cycle for system operation could be tested for more efficient performance and energy conservation during EVAs.

6. ACKNOWLEDGMENT

The author would like to thank the study researchers Dr. Kavya K. Manyapu, Dr. Pablo DeLeon, Dr. Leora Peltz and James R. Gaier for publishing this paper. It is a very valuable contribution to the space research and will surely aid in the future of Space Exploration. He would also like to thank his professor, Dr. Ruban who guided him in writing this review paper and in its formatting. The author is in turn also grateful to all other contributors of the original research paper. All the images, facts and figures have been taken from the original research and are accurate.

7. REFERENCES

[1] Dr. Kavya Manyapu, Dr. Pablo DeLeon, Dr. Leora Peltz and James R. Gaier, "Spacesuit Integrated Carbon Nanotube Dust Removal System: A Scaled Prototype", 48th International Conference on Environmental Systems, ICES-2018-278, 8-12 July 2018