Robotics Servicing Tool for Large Satellites

B. Maediger*, B. Langpap*, M . Doermer*, I. Ahrns*

*Airbus Defence and Space, Bremen, Germany
e-mail: {bernd maediger, bernd.langpap, manfred doermer, ingo.ahrns}@astrium.eads.net

Abstract

The situation in some Low Earth Orbits is currently characterized by two challenges. On one side the debris population in these orbits is growing rapidly, increasing the collision risk. On the other side there are a lot of new approaches to service or to maintain older, but operational satellites. In both cases the target objects are not prepared for these on-orbit servicing tasks, especially possible graspable objects are covered by Multi-Layer-Insulation or structural elements. These obstacles must be removed before the final servicing operation can be performed.

A promising new approach for these types of operations is the usage of a robotic manipulator. Here a robot-operated tool will be described allowing the adaption for many various servicing operations based upon a generic basic design and requiring single-arm operations only.

As an example the removal of the CFRP-boom of the solar panel of the Envisat satellite shall be considered.

1 Introduction

One solution to solve manipulation and handling tasks in robotic missions like space debris removal or satellite servicing is the usage of one or more robotic arms. Together with universal or dedicated grippers and smart robotic skills, which are available now on a sufficient technology readiness level (TRL) very sophisticated robotic operations can be conducted. But in most cases a two-hand operation can be advantageous, e.g. to hold a free-floating object and to operate it simultaneously, normally carried out on the basis of a two-arm design (as for human beings). For space applications such a two-arm approach is difficult to implement due to the higher mass budget and operational complexity, increasing the costs and the risks of a mission. Therefore in many space missions, including exploration missions, conducted so far, a one-arm design was used.

With the proposed tool the applicability of the one-arm-design can be extended significantly. The tool acts as a kind of robotic mounted gripper, but due to its modularity it can be adapted to the dedicated task without changing the overall concept or the main components. Currently the first design is used to cut and to remove the boom of the Envisat solar panel. Even in this concrete case the flexibility of the tool allows the integration of various cutting methods, e.g. either by thermal cutting or by a buzzsaw.

The basic concept of the tool is described in chapter 2, whereas the following chapters give an overview of the implementation of the various functionalities. Finally some test results regarding the usage of the tool for the thermal cutting of the Envisat-CFRP-boom are introduced.

2 Concept

For on-orbit servicing as well as for space debris removal a lot of different handling operations are required, ranging from simple cutting tasks up to removal of flexible materials (e.g. MLI) and screwing. Within the planned conduction of these operations by one robot arm grippers and/or tools are necessary to perform these tasks. Dedicated grippers or tools for each of these tasks would require a large set of components including a sophisticated tool-exchange system. Therefore the proposed tool concept tries to satisfy the needs for a large class of tasks with one tool attached to the flange of the robotic arm.

Due to the complexity of these servicing operations, the design of the tool is based upon a decomposition approach by splitting up the functions into more elementary operations with their own constraints and the specification of well-defined interfaces between these functions. Basically at least two functionality groups must be considered:

- Grasping
- Handling, like cutting, screwing, mounting

This enables the development of a dedicated solution for each operation and specification and the subsequent combination of these dedicated solutions into one integrated, complete system. Whereas the grasping element can be used in various operations the handling component must be adapted to the concrete task. Up to now the implementation of the handling component in the tool is fixed, later a tool-exchange system can be introduced, allowing the on-board configuration for various tasks. Based upon this approach, a wide variety of operations can be conducted with a small set of components.

3 Functions and its Implementation

Whereas the robotic servicing tool is a universal tool for one-arm handling purposes within this paper the application as cutting tool shall be described. But this description is used as example only and shall not restrict the application fields.

The robotic servicing tool in its cutting configuration is a robotic tool to supply an easy and safe way to remove large parts of a satellite in order to enable access to otherwise inaccessible or blocked areas and to stow the removed parts in a configuration allowing an easy and safe servicing or de-orbiting operation, especially by reducing the number and the dimensions of large extensions. As an example it could cut the boom of a solar array and stow the solar array safely on the main body of a satellite. Thus possible destruction of the solar array during de-orbiting can be avoided, all main masses are centered in the vicinity of the CoG and the de-orbiting operation can be designed more freely considering the otherwise possible damages of the target satellite. After the removal and stowage of the solar array a conventional docking operation between Servicer and launch adapter can be conducted, supported and guided by the robotic arm.

Acting as an enhanced gripper for the robotic arm, the tool integrates the following three basic functionalities:

- Grasping and Holding
- Servicing and Cutting
- Moving

The following Figure 1 shows the schematic structure of the robotics servicing tool. By using well-defined interfaces, the solutions for each of the functionalities can be swapped easily.

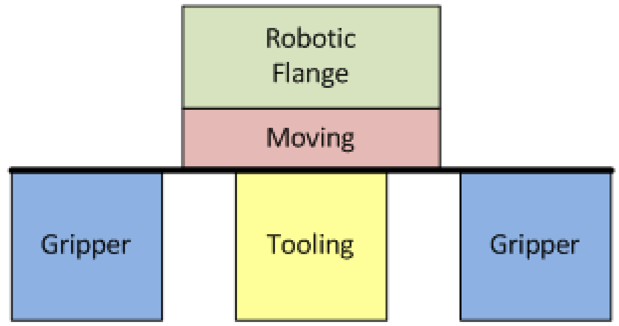

Figure 1: Architecture of the Robotics Servicing Tool

The following sections describe in operational order the function and characteristics of the design of each of the above listed functionalities.

3.1 Grasping and Holding

The grippers are designed to allow an easy grasping operation without requiring high robotic or GNC positioning accuracies. All elements are either passive or actuated by simple actuators. This concept reduces the probability of an error in the system through simplicity. Furthermore the proposed design ensures an abort- and retry-capability of the capture operation in every phase. Two grippers of the tool are attached to the boom. The two fingers of each gripper close through the force of a spring, similar to the functional principle of a clothespin (see Figure 2).

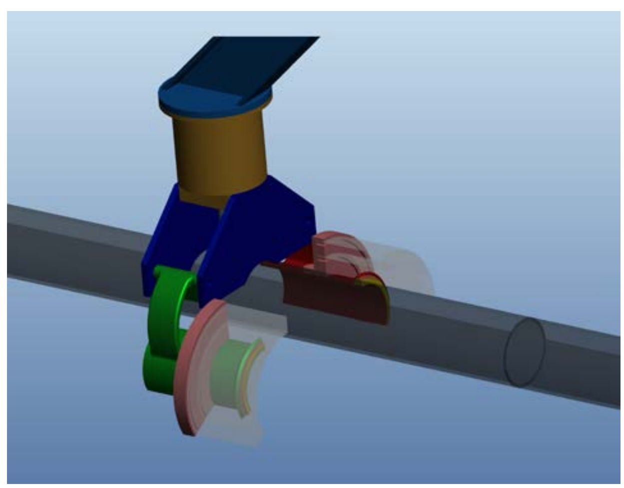

Figure 2: Concept of the Gripper

This ensures a safe and secure grip even in a powerless state. The gripping force can be adjusted through the spring, which ensures a safe grappling that withstands the loads during the deorbiting phase.

Opening the fingers is done via a motor in each gripper, which pulls the upper end of the "clothespin" together. Putting the gear in "neutral" or turning off the motor's power will result in a fast grasping of the gripper driven by the force of the spring.

3.2 Servicing and Cutting

The cutting and servicing part of the tool can be implemented differently suiting the needs of the operation, i.e. the enhancing mechanism part can be adapted according to the needs of the mission. For instance, if the mission objectives involve some kind of cutting of structural parts, a device that incorporates this functionality can be implemented e.g. a small buzz saw. In order to avoid any complication, such as friction welding and for the sake of simplicity and reliability, the proposed cutting mechanism here is a linear shaped charge that, once set off, forms a plasma jet cutting through the boom and the harness of the solar array without generating any significant debris This technology is well proven and similar methods are used in space missions already. Beyond that, using linear shaped charges offers a highly effective and reliable cutting mechanism, which is very light and simple to use.

3.3 Moving

Once the boom is cut, the two parts of the boom are still safely gripped through the grappling mechanism. Although a pre-compressed spring could be used to rotate the leg, using a motor in the joint connection of the two legs of the robotic tool, enables the predefined and controlled stowage of the disassembled part and allows for adjustment as well (Figure 3). Additionally, having this joint as the last joint in the manipulator arm enables the power supply and the data exchange with the cutting tool for control and monitoring reasons.

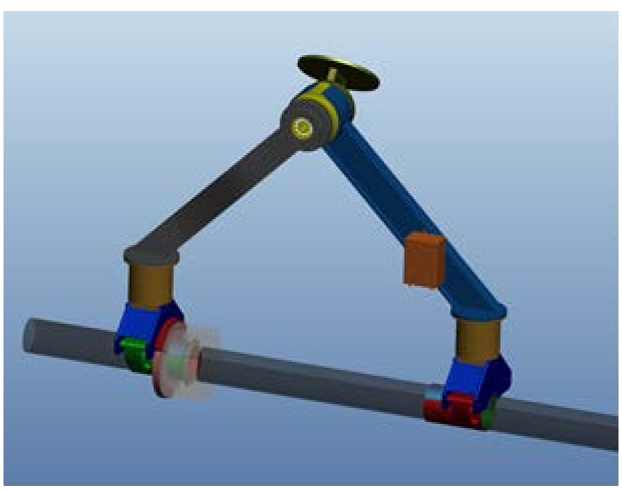

Figure 3: Joint connecting the two legs

4 Example: Envisat Solar Array Boom Removal

Launched in 2002, Envisat is ESAs largest civilian Earth observation satellite, which is now out of operation and non-responsive to any command (Figure 4). Being out of control and with a mass of around eight tons and flying on a sun-synchronous orbit, Envisat is not only subject to being hit by small asteroids and other debris, but and more critical, Envisat or parts of it (after a potential collision) endanger as well other operational Earth observing satellites and even future satellites aiming for the same advantageous orbital plane and altitude.

Figure 4: Artist's impression of Envisat ((C) ESA)

4.1 Objective and Proposed Solution

In order to prevent any accident, Envisat should be safely removed from orbit before it gets hit by any debris or asteroid. Being the part of Envisat with the most structural integrity, the launch adapter would be the ideal point, in order to grasp Envisat, to stabilize its spinning motion and to transfer the needed deorbiting impulse. Furthermore, being aligned to Envisats center of gravity (COG), deorbiting via the launch adapter would truly facilitate the deorbiting task for the GNC system.

But current observations revealed that the solar array, which could be rotated in order to adjust the solar arrays alignment towards the sun, ended up in a fixed position blocking the otherwise harmless access to the launch adapter.

In order to enable the access to the launch adapter, the solar array needs to be removed and secured. Therefore, the cutting tool can be adapted in order to grasp the mast of the solar array, cut it and store it in a safe position.

4.2 Adapted Tool Design

It is intended to utilize the Envisat launch adapter as interface element to regain complete orbital control of the satellite. But the access to the launch adapter is obstructed by the mast of the solar array. See figure 5 for the scenery there the servicing satellite is approaching the Envisat launch adapter.

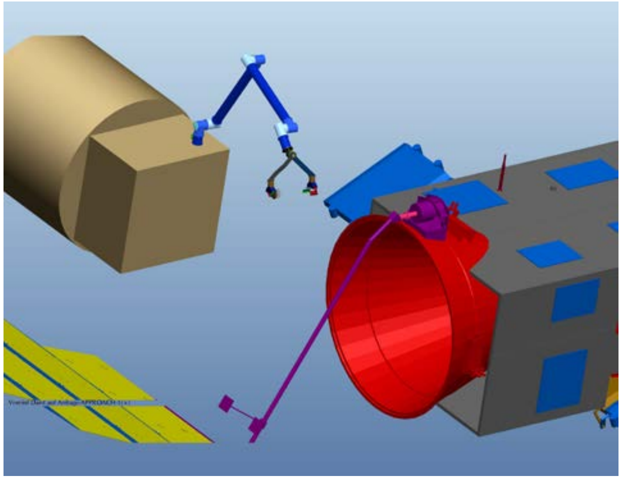

Figure 5: Approach to ENVISAT

In its current position the boom of Envisat´s solar array obstructs the approach path. To clear the approach area we propose a three step operation:

1. Attaching the cutting tool to the mast of the solar array -see figure 6.
2. Cutting the mast of the solar array including the inner harness by a pyro cut device
3. Turning the solar array in its new position- see figure 7

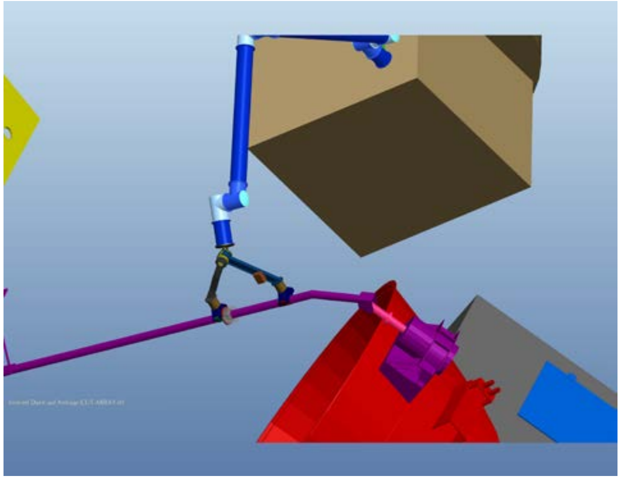

Figure 6: Attaching of the Cutting tool

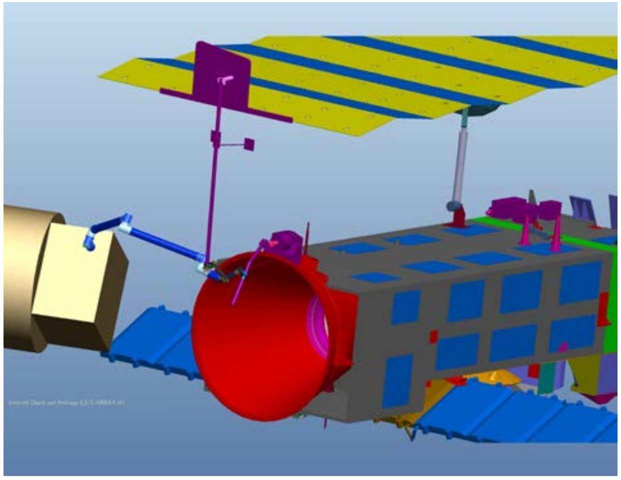

Figure 7: Turning the solar array in its new position

The dedicated robotic tool which establishes the physical contact between the servicer and the target satellites, break up a physical connection and provides a turning axis to reconfigure the configuration of the combined flight segment is given in figure 8, which shows the main elements of the Airbus Defence and Space capture and cutting tool.

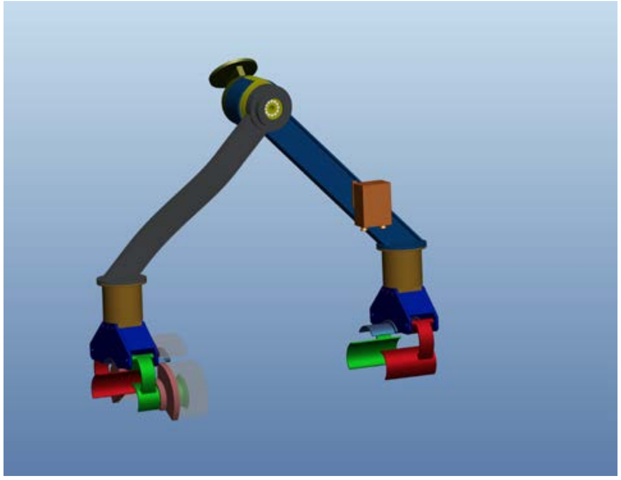

Figure 8: Airbus Defence and Space Cutting tool

The main subassemblies are:

- Gripper 1: attach and hold function
  at the end of the blue lever arm
- Gripper 2: attach, hold and cut function
  at the end of the black lever arm
- Joint: turning axis
  at the intersection of the two lever arms
- Camera: for visual navigation
  on the blue lever arm
- Lever arms: main structure
  blue and black lever- -
- Robotic flange: interface to manipulator
  rear side of the joint

This version of the tool is equipped with pyro cutting device as part of gripper 2. This is used to cut the structure grappled by gripper 2. The area around the cutting loads is protected by cages build up with metallic meshes. The cages also catches debris generated during the cutting process. There is an alternative option to fulfill the cutting function - mechanical cutting - under consideration. See figure 9 for a close up view of the cutting tool at the moment there a first contact between the mast and the gripper is established by the robotic arm. This phase is supported by visual tracking algorithm based on e.g. stereo camera images (other sensors are also under consideration) delivered by the stereo camera attached to the cutting tool (orange box on the blue lever arm)

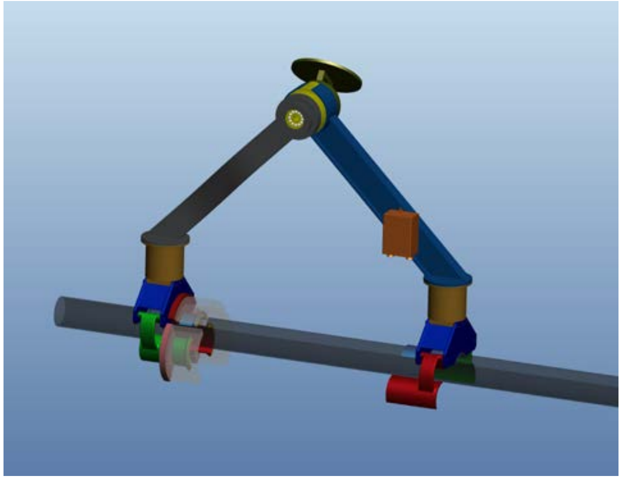

Figure 9: Close up view of first contact to mast

As soon as the tool is placed on its position on the mast, the grippers are closed - see figure 10. The gripper fingers are adapted to the grapple interface identified on the target satellite. Interfacing to other structures is possible by a replacement of the gripper finger with fingers adapted to the other interface. The gripper contacts must provide a physical contact which is able to transmit all operational mechanical loads induced by cutting, turning and maneuvering of the coupled spacecraft. The position and orientation of the cutting tool on the mast has to be confirmed by analyses on ground because the turning movement will be in the plane of the two lever arms so that the end configuration of the flight segment is determined by the position and orientation of the cutting tool on the mast. The tool can be repositioned by the robotic arm in case the desired configuration of the satellite cannot be reached.

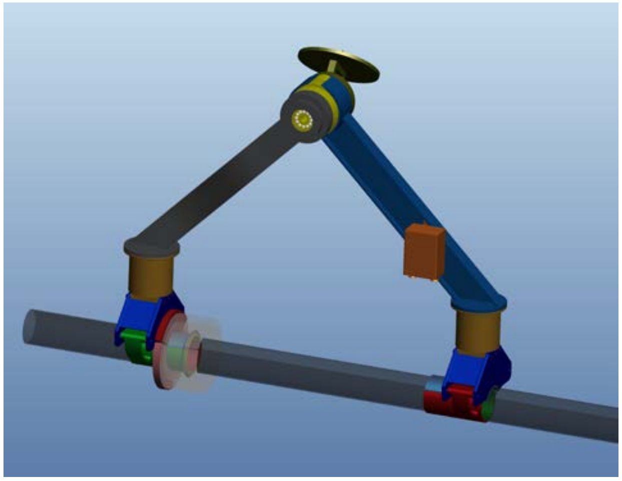

Figure 10: Closed Grippers

If the position and orientation of the cutting tool is confirmed, the cutting operation can be initiated. In this version of the tool the cutting function is integrated in gripper 2, see figure 11.

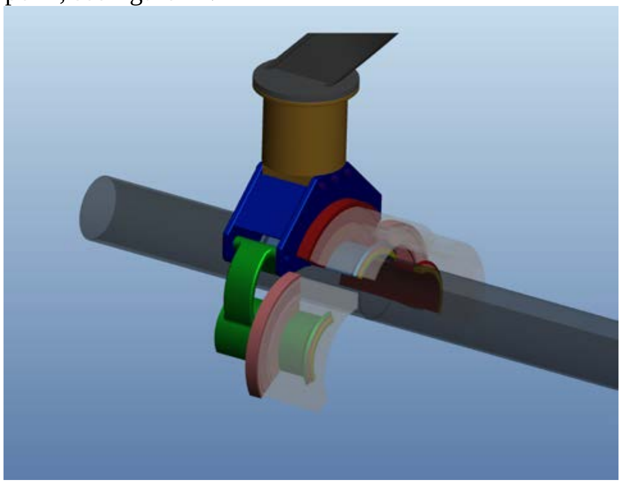

Figure 11: Close up view of gripper to with integrated linear shaped charges (LSC)

The linear shaped charges are divided in three parts. Each of them is integrated in grooves at the end of the gripper plates (three gripper plates form a complete gripper). In closed configuration they are arranged in form of a complete circle. To protect the surrounding components from the effects of the pyro-cutting e.g. small debris metallic caves are mounted around the cutting area, see figure 11. The cutting function can also be realized in form of a mechanical cutting (rather than thermo-mechanical with the LSC) device which utilizes the principle of a circular saw or similar. This version of the cutting function is still under development.

After the successful performance of the cutting operation, the turning function could be initiated. See figure 12 which shows the cutting tool in its fully turned (180°) configuration. Here an electrical driven joint is utilized for this function. Other drive principles are possible e.g. spring driven. But the electrical drive version offers the opportunity to (re) position and to adjust the position of the solar array in case the end position has not been reached successfully.

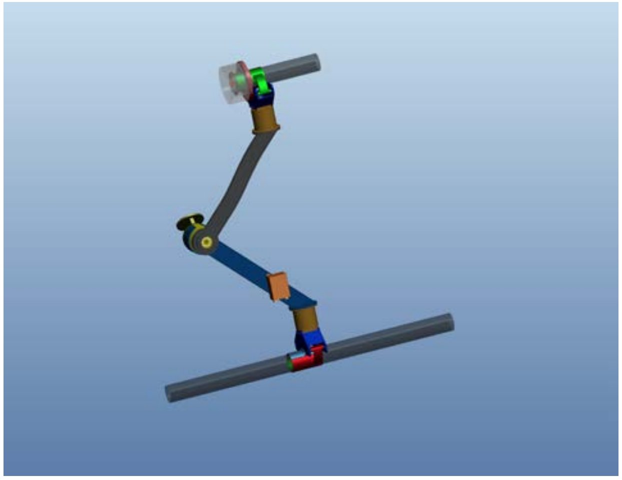

Figure 12: Turned configuration

5 Tests

In order to deal with the high amount of possible solutions for the different tasks at hand, the verification and validation of each mechanism of the integrated tool will be done separately in dedicated testbeds, i.e. there are multiple testbeds for checking the cutting and servicing components and other testbeds for the assessment of the grasping and moving mechanisms.

Once the feasibility of the mechanisms and their correct functioning is ensured, the different components can then be put back together through well-defined interfaces into the final assembly.

5.1 Cutting Testbed

This testbed is aimed for the analysis of the feasibility and the impact on the surrounding structure by cutting Envisats solar array mast using linear schaped charges (LSCs).

In a first step, the general applicability of LSCs is investigated. Therefore, a simple testbed has been used, which allowed the fixation of a wire-filled carbon fiber tube (13) and the attachment of a LSC (red).

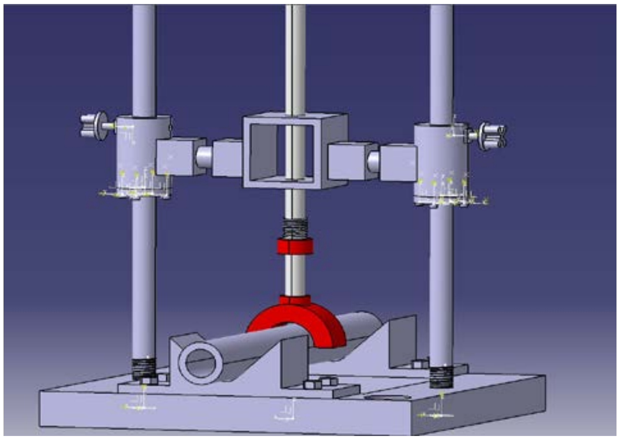

Figure 13: Cutting Testbed v1

The outcomes of this test are the amount of explosive needed for a successful cutting process (figure 14) as well as the requirement of a metal shield, which protects the carbon fiber from splitting. Additionally, a small steel mesh was proposed in order to collect the small particles of carbon fiber debris, which are generated by firing the LSC.

Figure 14: Cutting Result of a Carbon Fiber Tube

These results were then applied in the design of a second testbed, which is illustrated in figure 15. It comprises a stand, which is capable of grappling a carbon fiber tube with lockable grippers (red). The grippers are now extended by a metal shield (aqua) on which the LSC is mounted. The environment outside the cutting area is now protected from generated debris through a small steel mesh, which will be connected to the gripper finger later on.

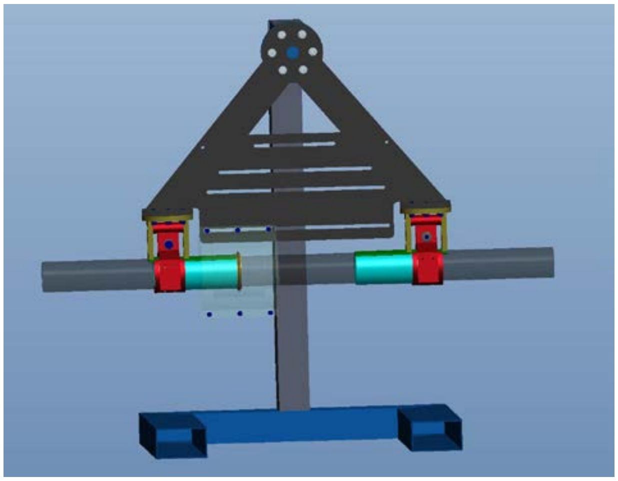

Figure 15: Cutting Testbed

5.2 Grappling and Moving Testbed

This testbed aims for the validation and verification of the grappling and moving process. It consists of two main systems, whereof the first one simulates the tumbling solar array mast of Envisat. The second one is the capture mean itself including visual sensors that needed for grappling the tumbling solar array mast. Once it is captured, the carbon fiber tube, which was held together by magnetic force prior capture, can now be separated and moved away.

6 Conclusions

The conducted tests have demonstrated the applicability of the proposed tool concept for the dedicated Envisat-application, using one robot arm only. This includes the basic concept, the dimensioning of the tool, the gripper configuration as well as the selected thermal cutting component. Additionally it could be shown that the cutting and stowing of the Envisat-solar array boom can be conducted with a robotic arm, equipped with an appropriate tool, building therefore a verified basis for a satellite removal mission. Further tests are currently under preparation to implement a buzzsaw as cutting tool too.

According to the currently envisaged application the development was focused on the usage of the tool as cutting instrument up to now. But due to the modularity other handling components can be integrated easily, either by modifying the handling instrument directly or to introduce an additional tool exchange system for the handling component.

The next steps include the integration of the tool-based robotic operations with visual navigation methods to demonstrate the whole operational sequence, beginning of the grasping of a tumbling boom and ending with the removal of the boom.

References

[1] "Long Term Evolution of Space Debris", 2010, Technische Universität Braunschweig

[2] Ogilvie, A., Allport, J., Hannah, M., Lymer, J., Autonomous Satellite Servicing Using the Orbital Express Demonstration Manipulator System, Proc. of the 9th International Symposium on Artificial Intelligence, Robotics and Automation in Space, iSAIRAS, Los Angeles, 2008

[3] http://www.darpa.mil/Our_Work/TTO/Programs/Phoenix.aspx

[4] Sommer, B., Automation and Robotics in the German Space Agency, 12th Symposium on Advanced Space Technologies in Robotics & Automation, Noordwijk, The Netherlands, 2013

Acknowledgment

The activities described in this paper were co-funded by the Space Agency (DLR Agentur), acting on a mandate from the Federal Government, grant no. 50RA1213.