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Drones4Safety

Research & Innovation Action (RIA)

Inspection Drones for Ensuring Safety in Transport Infrastructures

Specification of Harvester System

D3.1

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1 Executive Summary

The work of WP3 aims to develop a charging function for inspections drones that allows the recharge of the drone's battery from power lines of the electricity grid and railway catenary system. For practical application, the available power in relation to the current in the power line and the additional weight of the energy harvester for the drone is one of the interesting parameters to be determined.

The following deliverable is focused on the specification of the harvester system for inspection drones and is part of the WP3 – Harvester System. It describes the boundary conditions and requirements for the development of the harvester system.

After an "Introduction" of work package 3 in chapter 2 the next chapter "Application Environment" describes the boundary conditions for the harvester system, that goes into the fields of application and especially the energy sources for harvesting "Overhead power lines" and "Railway catenary systems". To get a better understanding for the requirements, in chapter 4 a short explanation of the fundamental concepts of the power conversion takes place. In chapter 5 than, the collection of all necessary parameters and requirements is represented. Not all parameters are already fixed with target values, because this has to be done during the development phase and depends on design decisions or external inputs respectively. Chapter 6 explains the concept charging electronics by means of a block diagram with all functional blocks to be developed. Chapter 7 addresses the mechanical part of the docking mechanism, separated in harvester systems using the AC or DC power sources. Due to the harvesting principle the docking is basically different.

Contents

Acronyms

Acronym	Description
AC	Alternating current
DC	Direct current
OPL	Overhead power line / Overhead high voltage line
RFL	Railway feeder line (wire)
OCL	Overhead catenary line
rH	Relative humidity
I/O	Input / Output
Li-Polymer / Li-Po	Lithium-(Ion-)Polymer

2 Introduction

A special requirement is to achieve the longest possible flight time in order to be able to use the autonomous operation efficiently. Since increasing the battery capacity will result in added weight, the conductor rope line was intended to serve as an energy source. Through an inductive harvester the drone can be recharged at AC lines and by direct contact to DC-lines. The drone docks to the overhead line with the harvester and charges the drone's battery. This limits the weight, but significantly extends the flight time and thus the operating time.

2.1 Goals of WP3

The aim of WP3 is to develop a recharge system for drones at overhead power lines (OPL) as well as railway feeder lines (RFL) during an autonomous inspection flight of bridges and railways. The idea is to harvest energy from the electromagnetic (stray) field from AC and DC lines by contacting the conductors and convert the voltage to the level needed for charging the drone's battery (see chapter 4 principles of harvesting systems).

For the later design of components essential tasks and derived functional requirements are:

- Harvest energy from (stray) field;
- Recharge drone battery;
- Weight of harvester (device incl. electronics) small enough to be carried by the drone;
- Autonomous charging (start and stop) by harvester electronics; Status of charging is provided to drone electronics;
- AC (inductive) harvesting with:
    - Control of the harvester (electronics) from drone's electronics to minimize magnetic forces and
    - Control harvester mechanics to open and close core by the main control unit of the drone;
- DC harvesting with:
    - Mechanics for contact to a DC-high-power-line at the railway catenary system;
    - Mechanics for mounting a docking station at DC powerlines;
    - Power and heat management for DC harvester and
    - Handling or avoiding of sparking during contacting.

3 Application Environments

3.1 Overhead power lines

From a technical point of view, high-voltage overhead lines provide easy access for drones. The drone can approach the line from the underneath and attach itself to the line. No additional energy is required for holding on during loading.

All AC lines that carry a large amount of current are suitable for the use of the principle of inductive coupling. These are usually medium voltage lines (up to 110 kV) and high voltage lines (up to 1000 kV).

Drones preferably choose the middle of a line segment where the conductor is horizontal as the point of docking.

DC overhead lines are more critical as energy sources for drone charging, because the high voltage is not manageable with necessary connection to ground for the DC-harvesting principle like planned in the railway catenary system. The approached addressed here, is the use of harmonics, which are generated in the inverter during the conversion of alternating current into direct current and are present on the line.

The structure and geometry of the high-voltage DC-line is the same as the AC-line and can be considered in the same way for docking.

3.2 Railway catenary systems

For the railway catenary system, both types AC and DC supply can be considered. In the AC case the application is similar to the overhead power line: Drones can dock to the feeder lines of the segments (figure 1). These are located outside the track on parallel lines.

In the DC case, the drone contacts the high voltage and establishes a connection to ground. Here, different locations for contacting can be selected. The following figures are showing examples of the catenary systems where the drone has to contact.

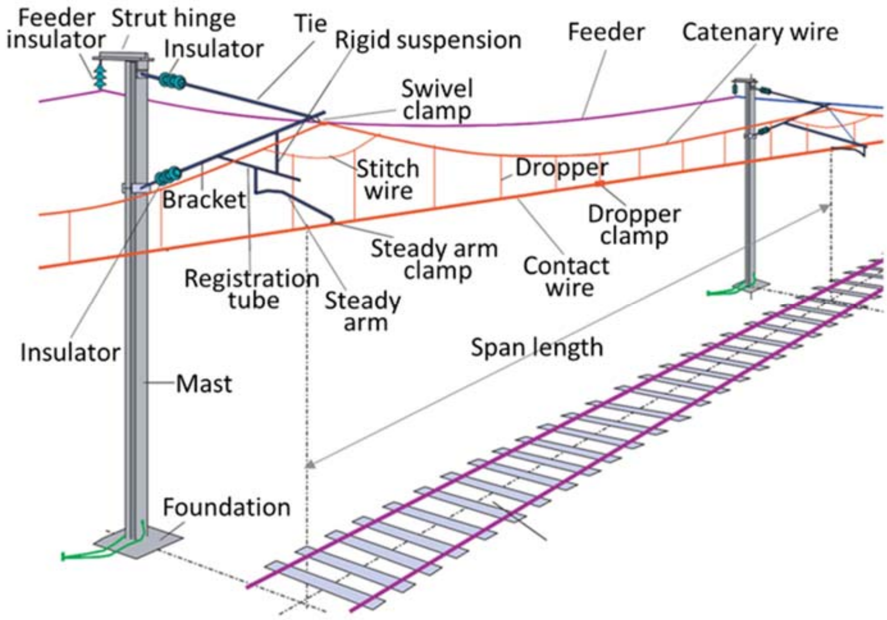

Figure 1: A span schematic of the OCL system [1]

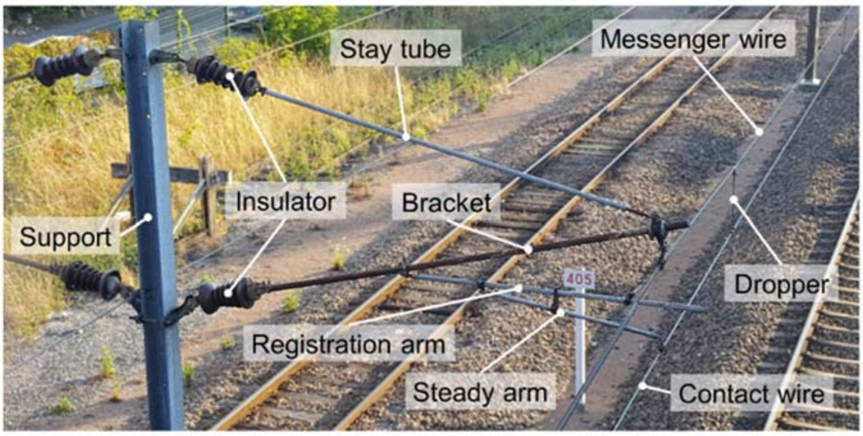

Figure 2: A Cantilever and its main components [1]

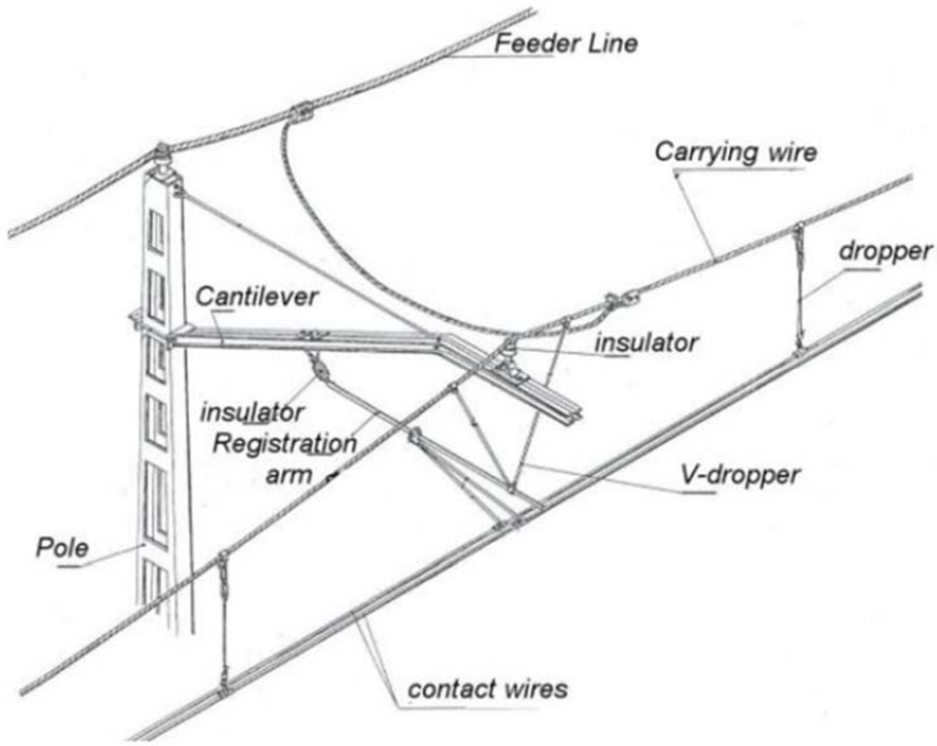

Figure 3: Flexible catenary elements [2]

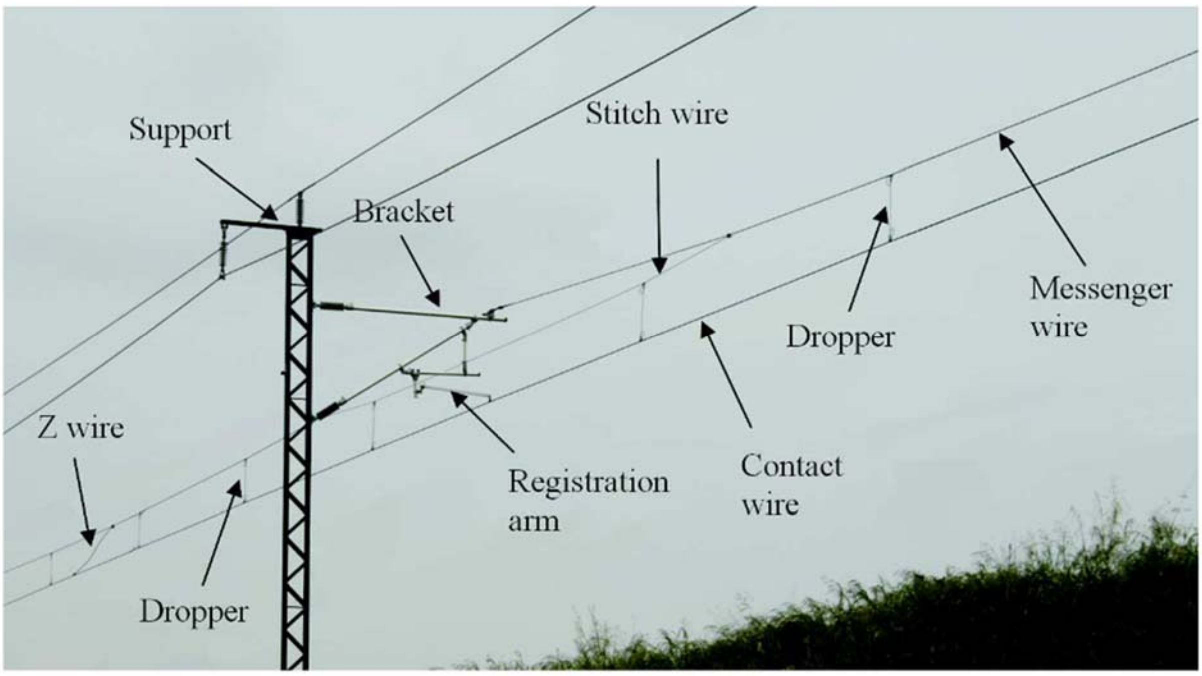

Figure 4: Real catenary with its main components [3]

4 Principles of harvesting systems

Based on the principle of inductive coupling, a harvester for the drone has to be developed. The concept is based on a clip-on converter whose core closes around the line when the drone docks with the high-voltage overhead line (Figure 5).

In contrast to the supply of sensor nodes, were this concept is widely in use, the harvester should provide a power supply that is preferably in the high-power range of more than 100 watts, whereby the weight of the core and the winding must be as low as possible, target figures are given in chapter 5.

The principle of inductive coupling will be evaluated for the harvesting from DC overhead lines. The AC proportion of the transferred energy is about 1%. Although this part is very small, a usable amount of energy can be expected, since the converter generates an alternating part with the harmonics at 600 Hz as the largest part. The frequency goes in square to the harvestable power. Thus, theoretically a similar power of the AC is achievable.

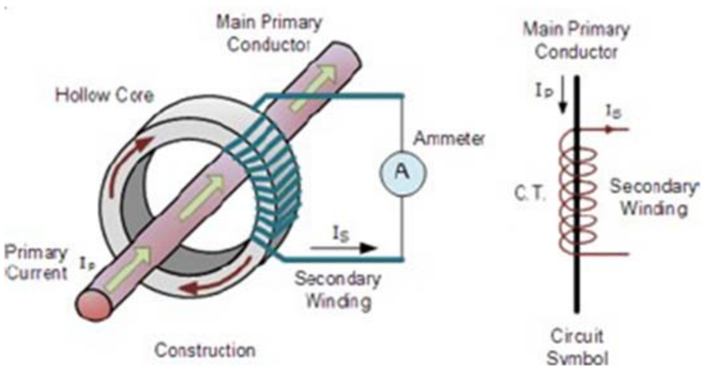

Figure 5: Concept of an AC energy harvesting system [4]

For the harvesting from DC lines the simple principle of a resistive voltage divider will be evaluated. Figure 6 shows this principle in a simplified diagram. The drone has to contact the ground and the high voltage line as well. The first resistor is presented by a Zener diode (voltage limiter) with the charging circuitry in parallel. The limiter determines the maximum manageable voltage Vin for the charger. The second part of the voltage divider is presented by a specific series resistor. At this resistance the remaining voltage drops. The converted power is power loss and is emitted into the environment as heat. In practice the resistor is divided into a series connection of many smaller resistors for better waste heat management.

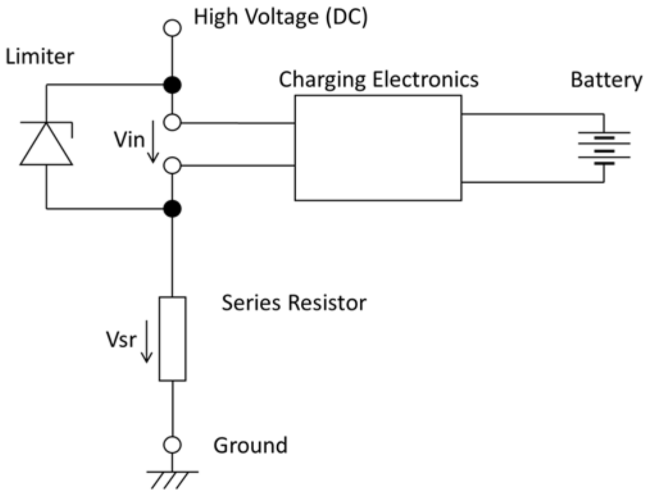

Figure 6: Concept of a DC energy harvesting system

5 Requirements and parameters for the harvesting system

This chapter covers all necessary parameters and requirements. Not all parameters are already fixed within the actual state of development with target values, because this has to be done during the design phase and depends on design decisions or external inputs respectively.

The listed parameters are categorized into three levels (plus one for additional information):

- M Essential requirement (or spec for test side)
- S Useful requirement (e.g., for a wider operating range)
- W Perspective requirement for the future (nice to have)
- I Additional information

Table 1: Operating Conditions

Parameter	Symbol	Min	Typ.	Max	Unit	Level	Note
Operating Temperature incl. battery	T_op	5	 10 - 30	45	°C	S M	*Critical is the temperature of the battery pack*
Ambient Temperature	T_amb	5		30	°C	M	
Weather, humidity	-		dry	70%rH		M	not condensing
Type of OPL	-		Single wire		-	M	
Type of Feeder Line			Single wire			M	
Type of DC Geometry			(see drawing in figure 7)			M	
OPL (Overhead power lines >100kV)							

Parameter	Symbol	Min	Typ.	Max	Unit	Level	Note
Diameter of Overhead Power line	Ø_opl	21		38	mm	M	
(Maximum) Continuous current in OPL	Ip_cont			800 1400	A	S W	
Short circuit current in OPL	Ip_sc			40	kA	S	For 1 second *(only for AC lines)*
Time of short circuit current in OPL	t_sc			1	s	S	
Average current in OPL	Ip_avg	tbd	400	800	A	S	*Important for setting the operation point of the system*
Net frequency OPL	fn_OPL		50		Hz	M	
RFL_AC50 (Railway Feeder lines/wires 50 Hz AC)							
Net frequency RFL_AC50	f_RFL_AC50		50		Hz	M	
Voltage range RFL_AC50	U_RFL_AC50		25		kV	I	
Average current in RFL_AC50	Ip_avg_RCW_AC50	tbd	700	tbd	A		*Important for setting the operation point of the system*
Continuous current in RFL_AC50	Ip_cont_RCW_AC50						
Diameter of Overhead Feeder wire	Ø_RFL	tbd		tbd	mm		
RFL_AC16 (Railway feeder lines/wires 16 2/3 Hz AC)							
Net frequency RFL_AC16	fn_RFL_AC16		16.7		Hz	M	
Voltage range RFL_AC16	U_RFL_AC16		15		kV	I	
Average current in RFL_AC16	Ip_avg_RFL_AC16	tbd		tbd	A		*Important for setting the operation point of the system*
Continuous current in RFL_AC16	Ip_cont_RFL_AC16						
Diameter of Railway Feeder wire	Ø_RFL	tbd		tbd	mm		
RC_DC (Railway catenary system DC)							

Parameter	Symbol	Min	Typ.	Max	Unit	Level	Note
Voltage Level RC_DC	U_RC_DC		1	3	kV		
Height of RC_DC	h_RC_DC	4			m	I	

Table 2: Electrical Parameter Harvester Electronic

Parameter	Symbol	Min	Typ.	Max	Unit	Level	Note
Voltage Level Status interface to drone electronics	V_stat		3.3		V	M	
Number of Status pins	n_stat	1	tbd	5			*Number and function of status pins are defined during development*
Number of control lines	n_ctrl	1	1	tbd			*Number and function of control lines are defined during development*

Table 3: Parameter of Drone Battery Pack

Parameter	Symbol	Min	Typ.	Max	Unit	Level	Note
Battery Pack charging current	I_charge			1 C* 5 10	A	I S	**depending on battery capacity* *RFL* *OPL* *(for Test System)*
Type of drone battery pack			Li-Po		-	M	*Protected cells*
Number of cells	n_cells		6	6	-	M	
Nominal Battery Pack Voltage	V_bp		22.2		V	M	
Final Charge Battery Pack Voltage		24		25.2	V	M	
Single cell voltage	V_cell		3.7	4.2	V	M	*typ. = nominal* *max = end of charge*
Connector to battery pack	P_bp		tbd				

Table 4: Non-Electrical Parameter of the Harvester

Parameter	Symbol	Min	Typ.	Max	Unit	Level	Note
Type of harvester core (AC)			Split core			M	(for OPL and RFL)

Parameter	Symbol	Min	Typ.	Max	Unit	Level	Note
Weight of harvester device incl. electronics	m_ha_opl			2000	g	M	
	m_ha_rfl			800	g	M	
	m_ha_rc_dc			tbd	g	M	
Size of harvester electronics incl. housing (width x length x height)	*w_ha*			tbd		S	
	l_ha			tbd		S	
	h_ha			tbd		S	
Size of harvester device OPL	*w_hd_opl*			tbd		S	
	l_hd_opl			tbd		S	
	h_hd_opl			tbd		S	
Size of harvester device RFL	*w_hd_rfl*			tbd		S	
	l_hd_rfl			tbd		S	
	h_hd_rfl			tbd		S	

Table 5: Other Parameter (just for information)

Parameter		Min	Typ.	Max	Unit
Voltage Level OPL			>100		kV
Voltage Level RCW_AC			15		kV

6 Power supply of the drones

The following diagram gives an overview on the power supply of the drone. All energy is provided by one battery pack with 6 Li-Polymer cells. The harvesting and/or charging status is provided by digital I/O Lines with a voltage level of 3.3V.

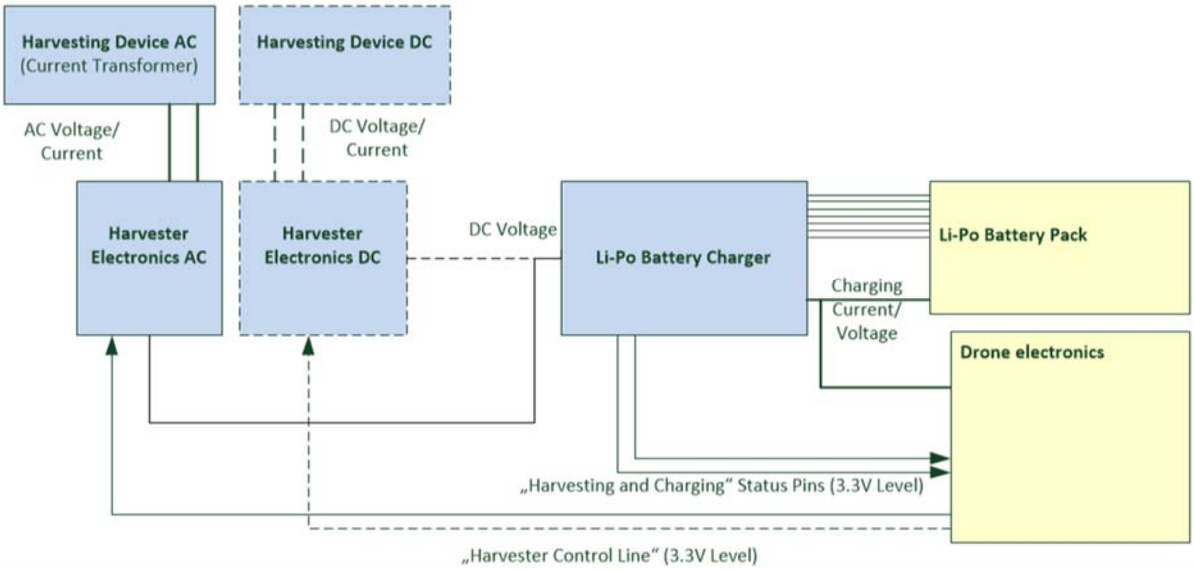

Figure 7: Functional diagram of harvester topology with drone interface

7 Docking Mechanics

The drone must be able to dock independently to the line. In addition to good algorithms for controlling the flight path, this requires high-precision sensors for local navigation in the detection of the cables and their approach under the influence of disturbance variables such as wind. High electrical and magnetic fields occur in the vicinity of the cable, and displacement or compensating currents can also flow at the first touch to the cable. The drone must have a high immunity to these influences. After closing the core around the conductor (AC-harvesting) or contacting the conductor (DC-harvesting), the drone can go into sleep mode and the battery can be charged.

7.1 Mechanism for attaching the drone to AC overhead power line

There are several requirements which have to be or should be fulfilled. Some of them are essential and some are needed for a best possible performance.

- No closed conducting loop through the core caused by the opening and closing mechanism (M)
- Closing the split core without a significant air gap (M)
- Good alinement of drone before closing the harvester core. During closing, the core must not touch the cable (M)
- Equipotential compensation between drone and high voltage line (S)
- Opening and closing mechanism has to overcome a certain amount of magnetic force (due to depending on the core geometry and material) (M)

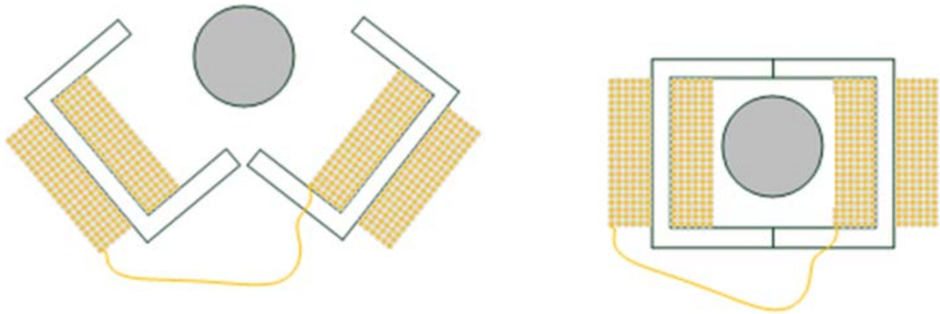

Figure 8: Cross section of split core halves opened (left) and closed (right) around the conductor

7.2 Mechanism for attaching the drone to DC railway catenary systems

For the harvesting from DC lines the drone has to contact the ground and the high voltage line as well. Figure 9 shows an example of the concept of docking. The drone first docks to an extension arm of the tower. This extension arm is also the ground contact. To contact in the next step to the high-voltage, the drone for example will be equipped with a moving part (e.g., telescopic arm), which is made from isolating material. When the telescopic arm is extended, a connecting cable is led to a part with high voltage. The series resistance of the voltage divider is integrated in the connection cable (see chapter 4 - principle of the harvester system).

There are several requirements which have to be or should be fulfilled. Some of them are essential and some are needed for a best possible performance.

- To avoid high voltage at the drone, the voltage divider must not be switchable and the contacts need to be realized with low impedance (M).
- The design of the contacting process of the high voltage has to consider sparking (M).
- The series resistor inside the connection cable has to withstand the heat emission and must not damage the drone when retracted (M)
- Even if the contact wire itself is not contacted, the influence of passing trains on the stability of the mechanics must be considered (S).

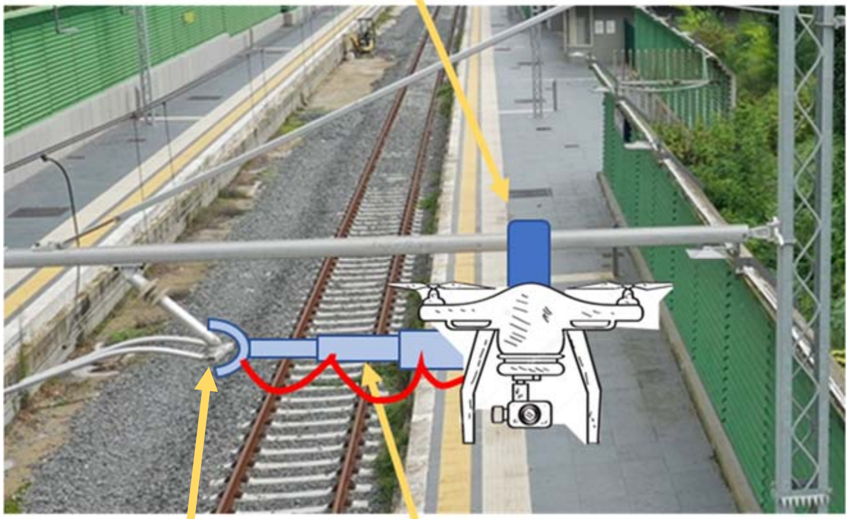

Figure 9: Concept for contacting the DC railway catenary system

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