Powering Electronic Instruments on a Rotating Shaft

Challenge ID: 9933885

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***Abstract* - The Bureau of Reclamation and its collaborators are seeking devices to provide direct current power for loads of up to 20 watts to electronic instruments on rotating shafts for hydropower generating units. Presently, no practical methods exist for continuously powering these instruments on a rotating shaft. Solutions can be novel approaches or can build upon existing methods or technologies**

Index Terms: Wireless power transfer; magnetic induction, Faraday's Law, Faraday Equation.

I. Introduction

In considering a non-contact means of power transfer to a rotating shaft, this solution proposes an induction system composed of a "belt array" of receivers, secured about the circumference of the rotating shaft. This array, composed of multiple modules, would continuously supply power to the instruments affixed to the shaft.

Wireless power transmittal has been shown to be somewhat problematic as environmental conditions and equipment packaging and maintenance of same often compromises the feasibility and practical application of this technology. This is not the case, with respect to this application and proposed solution.

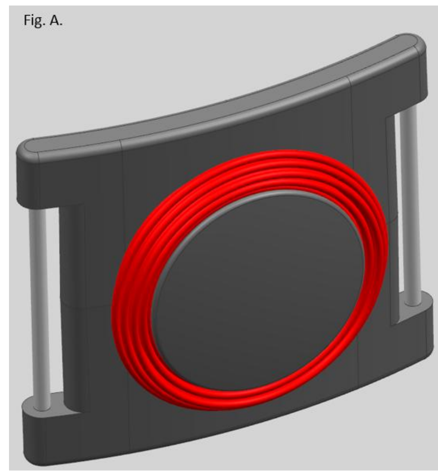
The proposal offers a low cost, low maintenance, portable solution to this problem. The theoretical and practical elements are well established, but this solution and design offers a unique perspective for the Bureau's consideration.

II. Power Induction

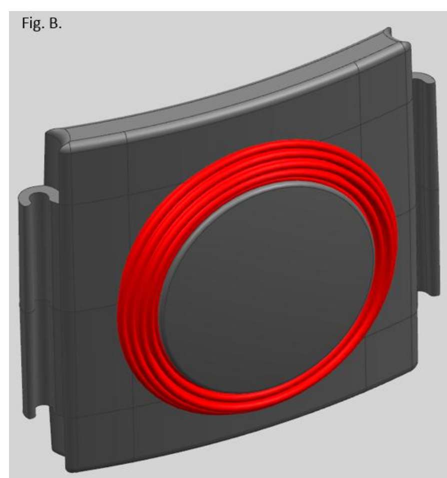
The system is composed of two parts, transmitter and receiver. The transmitter consists of three coiled modules placed in close proximity of the rotating shaft. The second part of the system is comprised of an array of antennas or receivers.

Once the transmitter is energized, power to the receiver or belt array will supply the instruments mounted to the shaft. This will be the case whether the shaft is static or under rotation.

Each element consists of a simple, coiled antenna circuit. The modules would be fabricated inexpensively as injection molded plastic parts. Figure A below illustrates the unit with a simulated coiled antenna loop.



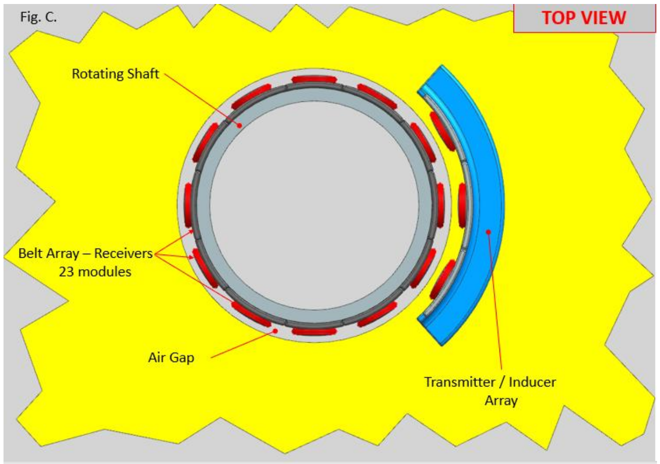
This module is alternately installed to a module of similar design, which allows the units to interlock as they are assembled about the circumference of the shaft. See figure B.



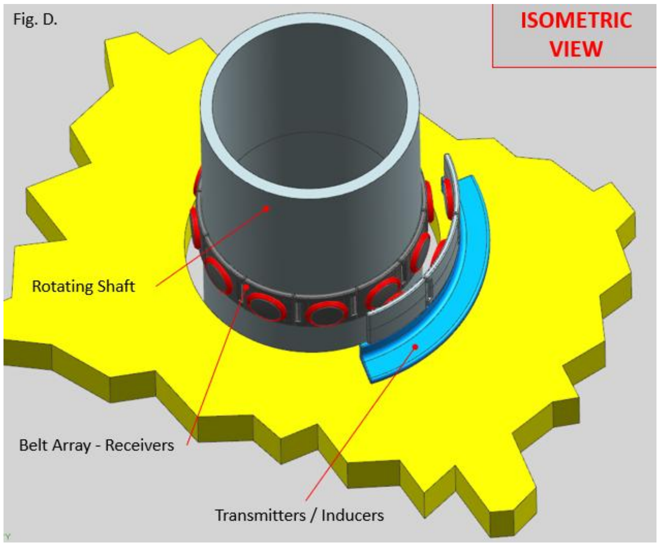
The "belt" would be clamped closed by a similar module (not shown). Further development on this element is needed, but the concept can be accomplished with additional fine tuning to this design.

III. System Overview

The system is designed with low cost and serviceability, and portability in mind. Figure C below illustrates a general overview. In this configuration, the belt array consists of 23 modules set in close proximity to the transmitter / inducer array.



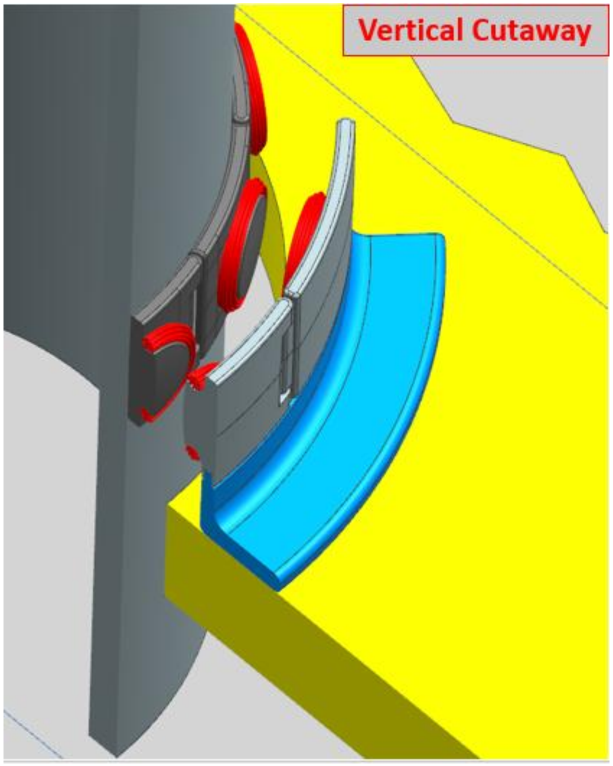
Additionally, figure D shows an isometric view for further clarity.



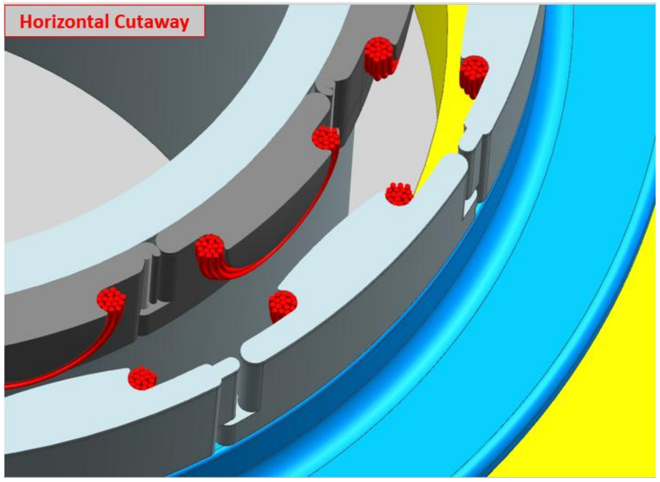
The Transmitter array would be energized by an external power supply and switchable at the base. It is composed of lightweight materials except for the base, itself.

Once the floor conditions are better established, a weighted base or anchored assembly could be installed. Alternately, the belt or antenna / receiver array would be assembled at the same height of the transmitter as seen in the vertical and horizontal cutaway views.

Vertical cutaway showing antenna / transmitter setup.



See Horizontal cutaway below.



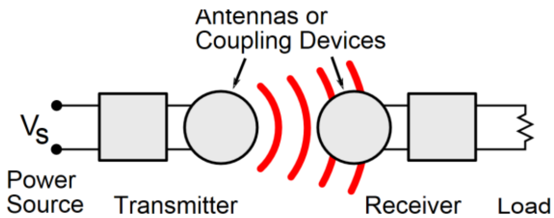
As conceptualized, this system will be low maintenance, low cost, and efficient. It can be modified, as needed depending on shaft diameters and the modules could be manufactured either through plastic injection molding or 3D printed as needed.

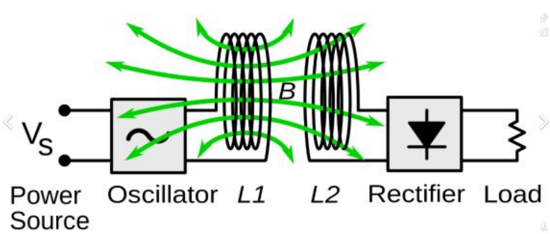
The antenna elements are linked, in series, using off the shelf wire, connectors, and clips. Lead wires and socket to power on shaft instruments could be affixed / secured using duct tape to the shaft. Theoretically, this arrangement should be capable of supplying power across a variety of voltage and amperage requirements within an environmentally controlled plant environment.

IV. Induction Theory

Extract from Wikipedia:

Wireless power transfer (WPT), wireless power transmission, wireless energy transmission (WET), or electromagnetic power transfer is the transmission of electrical energy without wires as a physical link. In a wireless power transmission system, a transmitter device, driven by electric power from a power source, generates a time-varying electromagnetic field, which transmits power across space to a receiver device, which extracts power from the field and supplies it to an electrical load.





Electric and magnetic fields are created by charged particles in matter such as electrons. A stationary charge creates an electrostatic field in the space around it. A steady current of charges (direct current, DC) creates a static magnetic field around it. The above fields contain energy, but cannot carry power because they are static. However time-varying fields can carry power. Accelerating electric charges, such as are found in an alternating current (AC) of electrons in a wire, create time-varying electric and magnetic fields in the space around them. These fields can exert oscillating forces on the electrons in a receiving "antenna", causing them to move back and forth. These represent alternating current which can be used to power a load.

The oscillating electric and magnetic fields surrounding moving electric charges in an antenna device can be divided into two regions, depending on distance D_range from the antenna. The boundary between the regions is somewhat vaguely defined. The fields have different characteristics in these regions, and different technologies are used for transferring power:

Near-field or non-radiative region – This means the area within about 1 wavelength (λ) of the antenna. In this region the oscillating electric and magnetic fields are separate and power can be transferred via electric fields by capacitive coupling (electrostatic induction) between metal electrodes, or via magnetic fields by inductive coupling (electromagnetic induction) between coils of wire. These fields are not radiative, meaning the energy stays within a short distance of the transmitter. If there is no receiving device or absorbing material within their limited range to "couple" to, no power leaves the transmitter. The range of these fields is short, and depends on the size and shape of the "antenna" devices, which are usually coils of wire. The fields, and thus the power transmitted, decrease exponentially with distance, so if the distance between the two "antennas" D_range is much larger than the diameter of the "antennas" D_ant very little power will be received. Therefore, these techniques cannot be used for long range power transmission.

Note: Transmission range for this system is designed to operate within a field gap of 2-3 inches (25-50mm) to be within resonance…

…Resonant inductive coupling, can increase the coupling between the antennas greatly, allowing efficient transmission at somewhat greater distances, although the fields still decrease exponentially.

Therefore the range of near-field devices is conventionally divided into two categories: Short range – up to about one antenna diameter: D_range ≤ D_ant. This is the range over which ordinary non-resonant capacitive or inductive coupling can transfer practical amounts of power.

Note: The proposed coil design would be approximately 4 in (approximately 100mm) in diameter… within a similar air gap between transmitter and antenna.

Mid-range – up to 10 times the antenna diameter: D_range ≤ 10 D_ant. (Antenna Diameter) This is the range over which resonant capacitive or inductive coupling can transfer practical amounts of power.

Faraday's law of induction and Lenz's law

Faraday's law of induction makes use of the magnetic flux ΦB through a region of space enclosed by a wire loop. The magnetic flux is defined by a surface integral

$$\Phi_B = \int_{\Sigma} \mathbf{B} \cdot d\mathbf{A} \, ,$$

Where dA is an element of the surface Σ enclosed by the wire loop, B is the magnetic field. The dot product B·dA corresponds to an infinitesimal amount of magnetic flux. In more visual terms, the magnetic flux through the wire loop is proportional to the number of magnetic flux lines that pass through the loop.

*When the flux through the surface changes**, Faraday's law of induction** says that the wire loop acquires an electromotive force (EMF) The most widespread version of this law states that the induced electromotive force in any closed circuit is equal to the rate of change of the magnetic flux enclosed by the circuit…*

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

Where $\mathcal{E}$ is the EMF and Φ_B is the magnetic flux. The direction of the electromotive force is given by Lenz's law which states that an induced current will flow in the direction that will oppose the change which produced it. This is due to the negative sign in the previous equation. To increase the generated EMF, a common approach is to exploit flux linkage by creating a tightly wound coil of wire, composed of N identical turns, each with the same magnetic flux going through them. The resulting EMF is then N times that of one single wire.

$$\mathcal{E} = -N\frac{d\Phi_B}{dt}$$

Generating an EMF through a variation of the magnetic flux through the surface of a wire loop can be achieved in several ways:

1. The magnetic field B changes (e.g. an alternating magnetic field, or moving a wire loop towards a bar magnet where the B field is stronger),
2. The wire loop is deformed and the surface Σ changes,

3. The orientation of the surface dA changes (e.g. spinning a wire loop into a fixed magnetic field),
4. Any combination of the above.

V. Conclusion

It is the opinion of the author that this solution, on its own or in conjunction with other similar solutions, provides a theoretically sound, practical and feasible answer to the proposed challenge.

Acknowledgment

This report was created in response to an Innocentive challenge. It is intended to be used for the sole purpose of evaluation only by the Bureau of Reclamation and its collaborators with respect to Innocentive Challenge ID: #9933885. The information contained within this report is intended as/for general information purposes only and do not constitute tested design engineering direction or other professional advice on any subject matter contain herein.

In Text References

In text references are denoted by italicized font and by note stating the origin of the referenced content. See Section ***IV. Induction Theory***. All information regarding this topic was taken from…

Wikipedia
(https://en.wikipedia.org/wiki/Wireless_power_transfer)

References

NO ADDITIONAL REFERENCES

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