Energy Harvesting Devices for Condition Monitoring
Applications of Pneumatic Combined Clutch-Brakes

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Abstract. In order to reduce unscheduled downtimes and maintenance costs, industrial machinery is being fitted with condition-monitoring systems (CMS) that measure important environmental factors and wear parameters of the machine. The electrical power required by these (often retrofitted) sensor systems can be supplied by energy harvesting devices. Pneumatic clutch-brakes provide an excellent application for both CMS and energy harvesting. These industrial machines transmit mechanical power through Kevlar brake pads which wear out due to the large frictional forces at play. The machine accelerates and decelerates from 0 to 1000 rpm and vice versa within 200 ms. This paper reports on energy harvesting devices that can use the large accelerations of the clutch-brake as an energy source to supply the CMS that measures the temperature and wear of the brake pads. A rotary system generates an average power output of 1.5 mW with the machine performing one clutch-brake action every four seconds.

1. Introduction
Clutches and combined clutch-brakes transfer the rotating movement of an electric motor to accelerate or decelerate a mechanical structure within a very short time. These devices may be pneumatic, hydraulic or electromagnetic. They are the key solution in machinery in different sectors, mainly where power transmission is needed: servo presses, lifting equipment, turbines, high-precision and planetary gears.

A combined clutch-brake as shown in Figure 1 (a) is a system with a dual braking and clutching function, where the functions may not both be activated at the same time \cite{1}. The torque transmission is realized through friction between brake pads made of Kevlar. In this works’ pneumatic device, the steel wheels of the system are forced onto each other when air pressure is applied and a clutch-brake action is performed. These brake pads are thus subjected to enormous forces and wear out over time. Traditionally, wear is monitored manually by qualified technical staff, which in turn requires machine downtime and thus increases costs. Condition monitoring of the temperature and wear of the brake

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pads allows optimum use of friction material and avoids unscheduled downtime and other malfunctions in the clutch-brake. Sensors for condition monitoring can be integrated on the clutch-brake. For the energy supply and the maintenance free operation of the sensor system, energy harvesting is required.

**2. Operating Principle**

Clutch-brakes come in a wide range of sizes and power classes. The boundary conditions for a typical clutch-brake include rotation speeds up to 1000 rpm and ambient temperatures up to 60°C. The clutch-brake action itself lasts less than 200 ms (acceleration to target value, deceleration to standstill, see Figure 2). If the application requires it, specific clutch-brakes can reach standstill within a rotation angle of 20°.

![Graph showing the rapid acceleration of a clutch-brake from 0 to 400 rpm.](image1)

![Graph showing the rapid deceleration of a clutch-brake from 500 to 0 rpm.](image2)

In the measurements presented in this work, the harvesting device is placed at a distance of 192 mm from the center of the clutch-brake. During standard operation according to the schematic in Figure 1 (b), the device performs one clutch-brake action every four seconds, i.e. the “clutched” and “braked” states are $t_2 = t_4 = 4 \text{ s}$. The areas marked in blue and green represent the phases where temperature (blue) and wear (green) need to be measured by the CMS. The aim is for the CMS to sample the temperature at a rate of 2 ms for a total of two seconds and the distance to the brake pad, i.e. the wear, at a rate of 2 ms for a total of 500 ms. The accelerating states $t_1$ and $t_3$ for an exemplary device are shown in Figure 2.

These large accelerations offer an excitation source for a kinetic harvester, but require a mechanically extremely robust design.
3. Experimental Data

3.1. Rotary energy harvesting approach

The first approach builds on the harvester device presented in [2]. The proposed rotational inductive energy harvester was heavily reworked to withstand the harsh excitation conditions (see Figure 3). The device consists of an eccentric mass mounted on a freely rotating wheel which houses 8 magnet segments of 45° angle and the back flux guide. The magnetic circuit thus forms a pendulum which can swing and rotate around the 8 coils that are placed at fixed positions within the housing.

During constant rotation of the clutch-brake, the pendulum of the harvester does not rotate against the coils due to centrifugal forces that hold it in position. Energy is mainly generated during the acceleration and deceleration phase. Table 1 shows the generated energy and the corresponding average power output using a 330 mF supercapacitor as energy storage for different number of clutch-brake actions and different motor speeds. It can be seen, that an average power of up to 1.7 mW can be achieved.

Table 1. Energy stored in a 330 mF supercapacitor and average power output [mJ] / [mW] for time periods corresponding to the number of clutch-brake actions N.

| RPM | N = 5   | N = 10  | N = 20  |
|-----|---------|---------|---------|
| 100 | 9.4 / 0.47 | 28.4 / 0.71 | 97.3 / 1.2 |
| 200 | 13.8 / 0.69 | 40.7 / 1.02 | 96.6 / 1.2 |
| 300 | 17.1 / 0.86 | 35.8 / 0.89 | 134 / 1.7 |
| 400 | 14.3 / 0.72 | 37.4 / 0.93 | 117 / 1.5 |
| 500 | 13.9 / 0.69 | 38.9 / 0.97 | 133 / 1.7 |

Figure 3. Rotational inductive energy harvester for mounting at the perimeter of the grey steel wheel in Figure 1.

3.2. Sensor System

Apart from the energy harvester, the CMS consists of a Cypress PSoC BLE chip with integrated microprocessor and low-power Bluetooth transmitter, a thermocouple and an amplifier for the thermocouple (AD8495), a distance sensor (BAW M12ME-UAD50B-BP01) with corresponding DC/DC-converter (ADP1612) and an accelerometer (BMA280).

Figure 4. (a) Schematic of the CMS showing all components. (b) Power consumption of the CPS for different operation modes from 300 mW when all sensors are working to 0.45 mW in sleep mode.

The schematic of the CMS is given in Figure 4 (a), while the power consumption for different operating modes is shown in Figure 4 (b). When all electronics are operating, i.e. during the distance measurement, approximately 150 mJ of energy are needed for a duration of 500 ms (equivalent to
300 mW). The temperature measurement and data transmission requires 40 mJ for a duration of 2 s (equivalent to 20 mW). In sleep mode, the power consumption of the system is 0.45 mW.

Measurements and data transmission are performed discontinuously. Table 2 lists the required amount of power that results for different cycle times. As an example, one measurement per hour results in an average power consumption of 0.5 mW during that hour. The aforementioned rotary harvesting device is thus able to power the CMS for several measurements per hour. This is a very satisfactory result, as the wear of the brake pads is minimal for such short time frames.

Table 2. Average power consumption of the CMS depending on the cycle time, i.e. the interval between measurements. At one measurement per hour, the required power is an average of 0.5 mW.

| Cycle Time (s) | Sleep Time (s) | Total Energy (mJ) | Average Power (mW) |
|---------------|----------------|-------------------|-------------------|
| 60            | 57.5           | 216               | 3.6               |
| 600           | 597.5          | 459               | 0.77              |
| 3600          | 3597.5         | 1809              | 0.5               |

4. Conclusion
In this work we reported on energy harvesting on pneumatic clutch-brakes. These devices require very robust harvesters because of their large accelerations. At the same this provides a powerful energy source for kinetic harvesters. In addition to a rotary harvester, a condition-monitoring system was developed, which monitors the temperature and wear of the Kevlar brake pads of the clutch-brake.

Depending on the operating mode, the power consumption of the CMS ranges from 0.45 mW in sleep mode up to 300 mW for the brief time span when all sensors are powered on. The rotary harvester generates an average power output of up to 1.7 mW and is thus able to supply the CMS for more than ten measurement phases per hour (see Table 2). This represent a sufficient measurement rate as the brake pads do not noticeably wear out in such short time spans.

An alternative to the rotational system is in development and is based on the linear harvesters in [3], in order to use the large available accelerations. First simulations indicate that up to 100 mJ of energy could be generated in a single cycle.

5. References
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