

# Warp Breaks Detection in Jacquard Weaving Using MEMS: Effect of Weave on Break Signals

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## ABSTRACT

This paper reports a study to detect warp breaks in terms of weave structure using MEMS accelerometer based detection system. The system is briefly described. The output signals of MEMS sensors, which were mounted on harness cords of a Jacquard machine, at the moment of warp yarn break and after the break for a broad range of basic weaves were acquired during weaving. The weaves investigated are commonly used in Jacquard weaving to form patterns. The strength of the MEMS output acceleration signals was analyzed in time domain. The results show that the system is capable of detecting warp yarn breaks for the broad range of weaves studied.

## INTRODUCTION

The weaving process represents a bottleneck in the sequence of woven fabric processes. To address this issue, weaving machine manufacturers and researchers undertaken two routes during last two decades. The first route targeted increase in speed through material selection and innovative design of machine parts and mechanisms. Last ITMA machinery shows indicate that the weaving speed may have reached its limit [1,2]. The second route targeted automation and several milestones have been achieved lately. These are automatic filling repair, automatic pattern change, adaptive control systems of filling arrival time in air jet weaving, quick style change, and pre-programmable variable weaving speed and variable pick density [1,2]. The repair of warp breaks remained, however, un-automated and still requires the weaving machine operator's intervention.

Woven fabric producers and researchers undertaken parallel investigations related to warp breaks. The research has, however, been limited to monitoring break frequency, location, and the reason associated with breaks in order to improve warp yarn quality through warp preparation and spinning processes

[3,4]. While this approach led to improvement in weaving efficiency, warp breaks still represent a major problem, especially for today's high-speed weaving machines. Researchers have been trying to develop commercial automated systems to repair warp breaks with no commercial success [5]. The traditional drop wire is still the common mean of monitoring the warp breaks by merely stopping the process when a warp yarn breaks. The disadvantages of the use of the passive drop wires have been discussed elsewhere [6,7]. The reason behind these disadvantages is the direct contact of the drop wire with the warp yarn. The goal of this study is to explore inexpensive methods to detect warp breaks using active nontraditional technique that would pave the way to automate warp break repair. To achieve the goal, a system that can detect warp breaks using MEMS accelerometers as non-contact to warp yarns sensors was developed for Jacquard weaving. The Jacquard weaving was selected because Jacquard fabrics markets include industrial, decorative, upholstery, which are niche markets, and the warp ends are individually controlled. The system was tested and used to detect warp breaks running Plain, 2x2 RH Twill, 4x4 RH Twill, and 8-Harness Satin weaves. These weaves are commonly used in Jacquard weaving to create intricate patterns. Intentional breaks were detected by the system for the weaves studied. Brief description of the system is provided here. More details, procedures to test the system to validate its function, and additional experimental data are published elsewhere [6,8].

In this paper, we focus on reporting the effect of weave on the output signals of the MEMS accelerometers. The output signals of MEMS sensors were analyzed in time domain in terms of weave construction. The purpose here is to identify the range of applicability of the developed system.

## SYSTEM DESCRIPTION

The full system consists of MEMS accelerometers as

sensing devices, data acquisition hardware, and data analysis software. *Figure 1* shows a schematic diagram of the warp break detection system. Selected MEMS accelerometers for this research are characterized by their small size, lightweight, and the ability to detect motion in two orthogonal directions. MEMS accelerometer sensors are active devices and their signal could be used to detect and identify warp break locations. Seyam et al [9] developed a system to locate a warp break based on the MEMS break signal detection using the fact that each warp yarn in Jacquard weaving is addressed. Additionally, the signal could also trigger a sequence of actions to activate automated warp break repair elements.

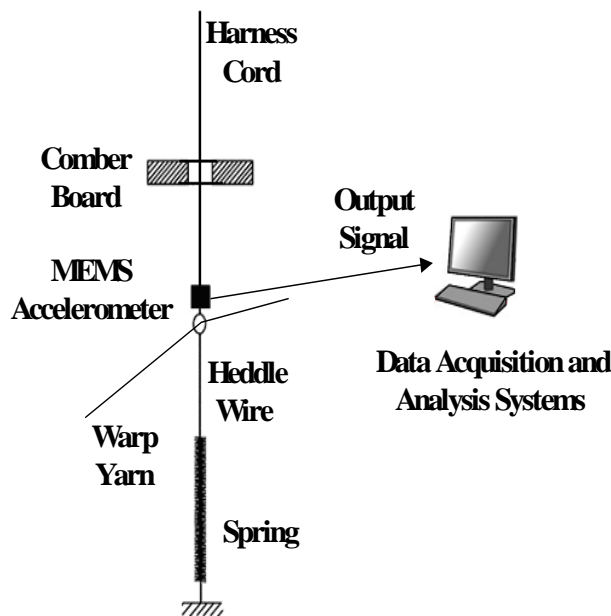


Figure 1. Schematic diagram of the warp break detection system

In order to mount the MEMS accelerometers, the backside of each MEMS accelerometer, was pasted by glue along a groove created on a heddle wire (connected to each instrumented harness cord) to accommodate the sensor.

The MEMS accelerometers were wired to a data acquisition board which is especially designed for counter-timer (event counter). MEMS accelerometers generate pulse-width-modulation (PWM) signal, which is transferred to data acquisition board. The counter/timer is a basic unit of hardware functionality on a measurement device. The more counter/timers there are on a device, the more counting/timing operations the device can

simultaneously perform. Two millisecond based pulse width (550 Hz) of MEMS accelerometer were easily measured in that each 32-bit counter can count up to  $2^{32}-1$ , and pulse widths were measured with 80 MHz resolution. Counter/timer which is represented as low-to-high, or high-to-low, transitions of the input signal can count events as they take place.

A program was developed to acquire PWM and analog signals from MEMS sensors using LabVIEW software. During running trials, the program read the signals and saved the data as ASCII text files according to their time log. The data were analyzed offline. Since the MEMS accelerometer provided a pulse width modulation (pulse-width and semi pulse-width), the modulations had to be converted into acceleration.

The selected MEMS device is a 2-axis acceleration sensor on a single integrated circuit (IC) chip. The MEMS accelerometer was mounted so that its vertical acceleration is measured in the direction of the harness cord below the comb board. The horizontal acceleration is measured in the direction perpendicular to vertical acceleration direction.

## EXPERIMENTAL

### Materials

The warp and filling specifications used are:

Warp Density:	31 ends/cm
Pick Density:	11.8 picks/cm
Warp Yarn Count:	124 tex
Filling Yarn Count:	31.2 tex
Warp Yarn Type:	polyester flat filament
Filling Yarn type:	cotton ring spun

### Weave structures

An experiment was conducted to investigate the effect of weave structure on MEMS output signal prior to yarn break, at the moment of break, and after break. The weave structures selected are plain, 2x2 RH Twill, 4x4 RH Twill, and 8-Harness Satin weaves. These weaves represent broad range of basic weaves used in developing Jacquard patterns. Jacquard patterns are formed using combination of basic weaves. For example, a warp yarn in Jacquard weaving forms 8-Harness Satin weave in certain area of the pattern, then the yarn forms 4x4 Twill weave in another section of the pattern. The switch from a basic weave to another continues until the repeat is completed. In other words each warp yarn in Jacquard weaving forms several basic weaves in different areas of the pattern. The selected weaves were constructed to characterize weave effect on the MEMS signals. Another example is the new trend in

weaving shaped fabric using Jacquard weaving. Kitamura et al [10] developed seamless airbag, which need to be woven using Jacquard shedding system to provide the shape of the airbag. The airbag is a double cloth with woven stitches around the airbag shape. Airbags are woven using plain and 2x2 basket weaves.

It is worth mentioning here that if the warp break signal for the selected four weaves are detectible by the system, then warp breaks for any weave could be detected since a weave is formed by combination of floats and weave interlacing. In other words, if warp breaks can be detected at weave interlacing and floats, then the break can be detected for any weave.

The warp yarn tension was kept constant at 1 cN/tex, which is within the practical range used in the industry. We used ELTEX single-rapier weaving machine equipped with a Staubli Jacquard head. This machine is used for developing samples and its speed is limited. The weaving speed was kept constant at 245 picks/min. While this low speed machine was used due to availability, the MEMS accelerometer and other hardware and software components of the system are capable of output and acquiring data from modern high-speed weaving machines. As indicated earlier, the MEMS accelerometer used in this research has very high resolution of up to 80Mhz, which can output 80 mega data points/second. Prior to mounting the MEMS sensors on Jacquard machine, we evaluated two MEMS sensor using a test-bed device with two harness cords. The harness cords were moved in plain weave motions and ran at a speed equivalent to 400 picks/min [11]. The data acquired in time domain indicated that the MEMS sensors are responding as expected.

### **Procedures**

Three different runs for each weave (a total of 12 runs) were conducted. For each run time domain data were acquired from MEMS accelerometers. The following steps were conducted for each run to reach to stability of warp tension since keeping weaving machine idle for long time causes the warp to creep and its tension to reduce:

1. Feed an experimental warp yarn from the creel to each instrumented harness cord (four)
2. Run the weaving machine
3. Using a tension meter, monitor one of the experimental warp yarn tension for 3-5 minutes until the set value is reached (1 cN/tex). The tension was measured by a tension meter, type DTMX-500 with

sensitivity range of 0.1 to 500 cN, and at a 2 Hz sampling rate.

4. Start data acquisition from MEMS sensors
5. Break experimental warp yarns using pair of sharp scissors (simulation of a missed warp yarn)
6. Stop weaving machine and data acquisition

The warp yarns threaded through the instrumented harness cord were intentionally cut in the area between the web roll and harness tie using sharp scissors. Cutting the yarn by sharp scissor simulates missing ends. Missing ends takes place during warping and sizing processes. The warping process is a high-speed process and cannot be stopped immediately when an end breaks due to high inertia of heavy parts of the machine. While each end is monitored by a sensor that stops the process when an end breaks, many of these ends disappear quickly on the beam (in case of direct warping) or drum (in case of indirect warping) before they can be tied. During sizing, it is impossible to mend broken ends since the process is not allowed to be stopped otherwise over drying of warp sheet could take place and sizing material would shed during weaving a matter that causes many breaks. The sizing machine may run at creep speed at the start of the process or untangle warps due to a broken end.

Care was taken when intentional cuts were performed to avoid any effect on the signal of the sensors. The use of sharp scissor and the location of cut, which was close to the web roll, did not allow such effect. In previous publications [12], we presented warp breaks detection due to high strain (strain induced breaks) by underfeeding the warp yarns threaded to the instrumented heddle wires.

### **RESULTS**

*Figures 2 through 5* show the plots of time domain data of horizontal acceleration due to vibration (shown in black), and vertical acceleration given to the harness cords by the shedding motion (shown in grey) for the four weaves investigated. Additionally, the figures show the ideal vertical acceleration in grey broken line to identify the nature of motion at the time of break. The data of *Figures 2-5* were collected before warp yarn intentional break, at the moment of the break, and after the break. In *Figure 2* (plain weave) the moment of yarn break is clearly seen at 8.14 sec from the horizontal acceleration data and it is characterized by high acceleration value. It is also observed that regardless of weave the break moment is obvious with high horizontal acceleration value in each break occurrence. The acceleration values continue to be high over a noticeable period of

time. It should be mentioned here that in case of plain weave the harness cords are in continuous motion (dynamic) as it can be seen from the data of the vertical acceleration in *Figure 2*. On the other hand 2x2 R.H. Twill, 4x4 R.H. Twill, and 8-H Satin weaves the harness cords are moved up (or down) followed by a dwelling (static) as it can be seen from *Figures 3-5*. The break signal was appreciable from the horizontal acceleration data for all weave types regardless of the time at which the yarn was cut and whether the harness cords were moving (dynamic mode) or stationary (static mode).

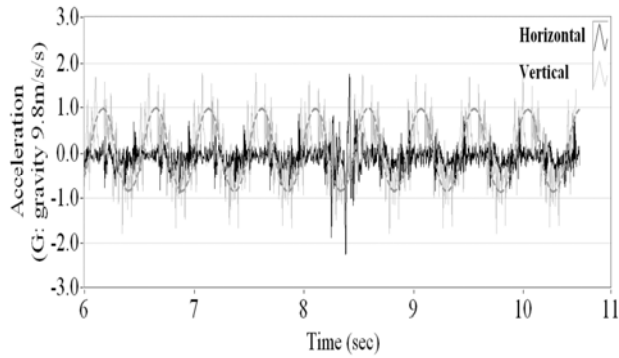


Figure 2. MEMS output signal for Plain weave

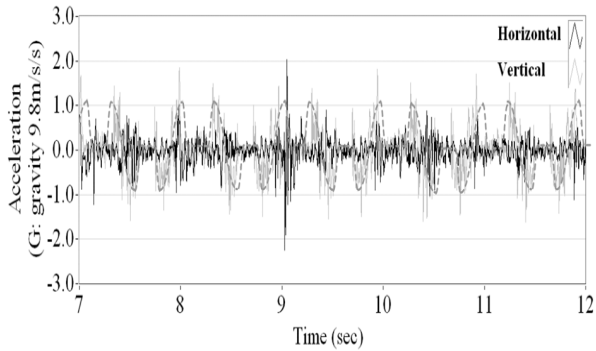
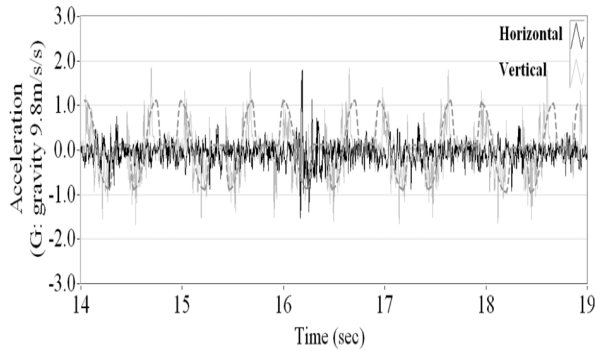


Figure 3. MEMS output signals for 2x2 R.H Twill weave  
Top graph: break in dynamic mode  
Bottom graph: break in static mode

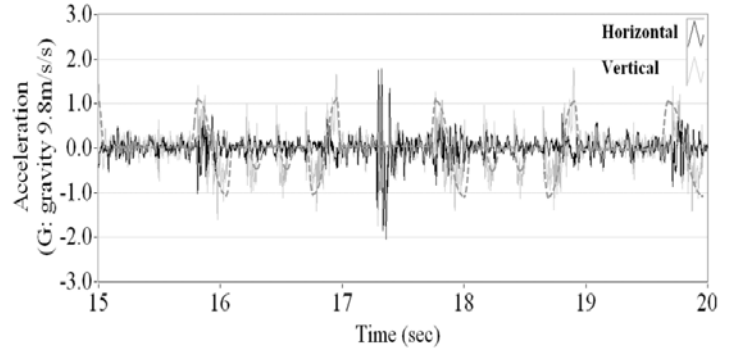
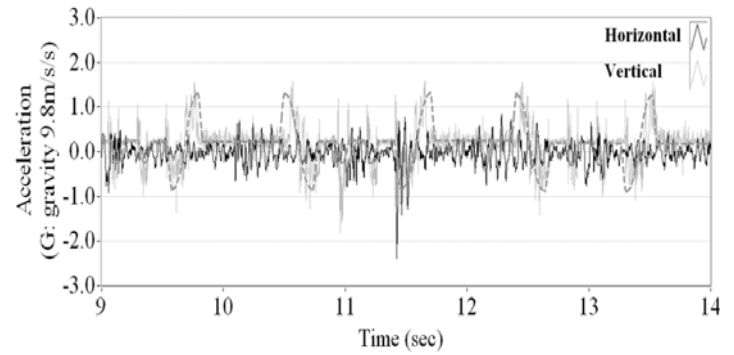


Figure 4. MEMS output signals for 4x4 R.H. Twill weave  
Top graph: break in dynamic mode  
Bottom graph: break in static mode

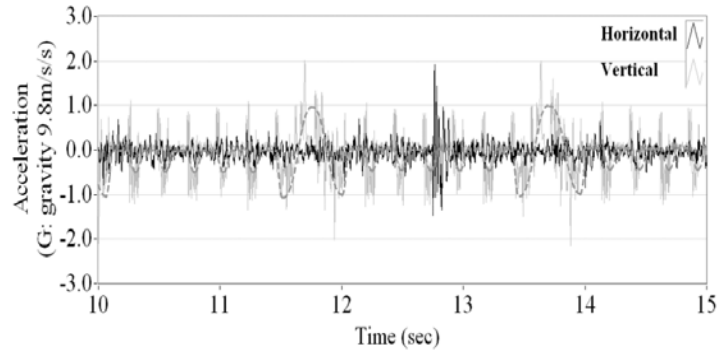
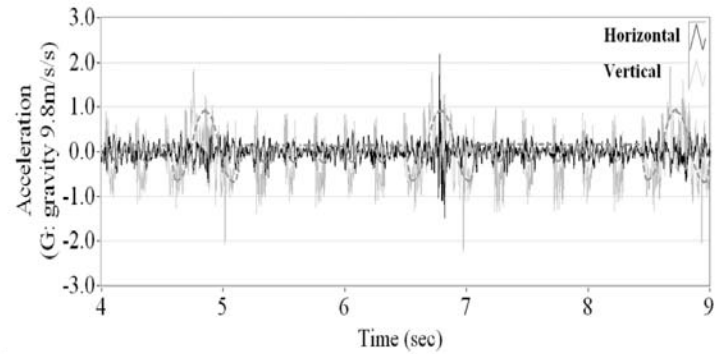


Figure 5. MEMS output signals for 8-Harness Satin weave  
Top graph: break in dynamic mode  
Bottom graph: break in static mode

The results of *Table I* show the maximum peak of horizontal acceleration at the moment of break for the four weaves, the average of positive peaks before break, and the average of negative peaks before break. It seems from these results that the static breaks showed higher peak values than dynamic. This may be due to the interference between the vertical and horizontal movements of the harness cords in case of plain weave (dynamic mode). Additionally, the results of *Table I* illustrate that the maximum peak at break is much higher than the average peaks before break.

The data of the vertical acceleration of *Figures 2-5* at the moment of break is not significant to be observed (data of horizontal and vertical accelerations were plotted separately to arrive to this observation). This could be attributed to the fact that the harness cords are rigidly supported from the top and the existence or absence of the yarn did not affect the harness cord law of motion significantly. On the other hand, the horizontal vibration increased due to the fact that the presence of the yarn supports the harness cord at the heddle eye and to some extent restricts the horizontal motion. Once the yarn break occurs the harness length supported is much longer as compared to the presence of the yarn a matter that increases the motion amplitude in the horizontal direction. Moreover the sudden vanishing of the yarn tension component causes the spring to be suddenly compressed (when warp yarn is in the negative zone of displacement) or tensioned (when the yarn is in the positive zone of displacement) a matter that causes the spring to bounce. The bounce of the spring causes the most flexible element (the harness cord) to buckle. Buckling, (or slackness) of the harness cord and free harness cord without support combined with the vibration caused by different weaving motions lead to appreciable harness cord horizontal vibration which is transferred to the heddle wire (or MEMS accelerometer). Theoretical basis of vibration of harness cord (or string) in terms of its length is provided in references [6,12].

Based on the above, the size of a hole in the comber board could be optimized to increase the horizontal motion and allow for better break detection if other factors hinder the detection.

TABLE I  
Highest horizontal acceleration peak at yarn break and average peaks before yarn break

Weave Structure	Average Peaks Before Yarn Break* (G)	Highest Peak Acceleration at Yarn Break (G)	Mode
Plain	0.7261/0.8394	1.9935	Dynamic
2x2 R.H. twill	0.6190/0.8485	1.8017	Static
4x4 R.H. twill	0.8937/1.0078	1.8858	Static
8H warp satin	0.6715/0.6526	1.9152	Static

\* Absolute values of positive/negative accelerations

### AUTOMATION OF WARP BREAK REPAIR

In this paper we presented a viable method to detect warp breaks using MEMS sensors in Jacquard weaving. Each MEMS sensor (or each warp yarn) is addressed in Jacquard weaving. We also developed warp break location finder using servo table that was programmed to point at the location of a warp break that could be connected to the MEMS sensors and located at the front of the weaving machine [6]. The MEMS and servo table modules achieve significant time reduction since finding the location of a warp break takes significant time from the operator. Further, we conducted a study addressing warp break location and frequency in Jacquard weaving and it was found that 75% of the breaks take place between the cloth fell and the harness tie [9]. This indicates that the yarns are still threaded in the heddle wires eyes.

It is envisioned that automatic warp break repair is within reach using the following steps:

- MEMS sensor detects the break and its location and signals to the warp location finder.
- Warp sheet is leveled
- Jacquard head controller raises the harness cord of the broken end.
- Improved warp location finder with a drawing-in needle moves to the location and the drawing-in needle goes through the reed dent of the broken end.
- The broken end is picked up by a robotic arm (the existing system used to repair filling yarns could be modified to do the task as well) and presented to a splicing system (splicing is standard in winding machine) to elongate the yarn.
- The elongated yarn is presented by the splicing arms to the draw-in needle
- Warp yarn is held under tension by pressing the yarn against the fabric.
- Weaving resume automatically.

In case of missing yarns or yarns broken at the back, the robotic arm will detect the absence of the yarn from the harness cord. The repair in such cases is extremely difficult and automation would be costly. The system in such cases points to the location of break and flags the weaving machine (as done today by light) so that the weaver can attend it.

## CONCLUSIONS

It was found that the difference between MEMS sensor vertical accelerations before and after warp breaks is not significant. The difference between the horizontal accelerations before and after warp breaks is, however, significant for the range of weave structures studied and hence for any weave. This leads to the conclusion that using MEMS accelerometer sensors in Jacquard weaving is a viable technique to detect warp breaks.

While the warp breaks were detectable for the experimental range reported here (effect of weave using one type of yarn under a certain tension), additional research is needed to find out whether the system works for other experimental conditions. We are conducting additional experimental work to study the impact of warp yarn type and warp yarn tension on the output signal of the MEMS sensor to identify the range of applicability of this system.

It is believed that an automated warp break repair system could be developed using MEMS sensors combined with drawing-in needle attached to the servo table (warp break location pointer) and existing splicing and robotic arms used currently in winding and weaving technologies.

## ACKNOWLEDGEMENT

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