

# How to improve precision of steel strip speed measurement

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## Introduction



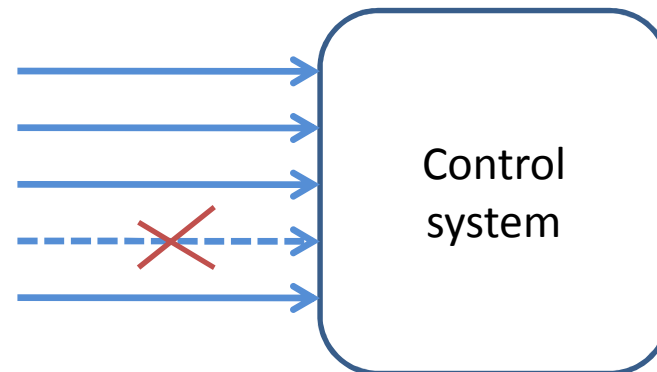
- **Speed measurement – a subtask of ProBaSensor project**
- **ProBaSensor – R&D project supported by Eurostars Programme**
- **Eurostars Programme – programme of EUREKA**  
intergovernmental network oriented to support of innovation in industry, specialized in SMEs (Small & Medium Companies)
- **project funded by MŠMT (Ministry of Education)**

## ProBaSensor Project

- **Project participants:**
  - **COMPUREG Plzeň, s.r.o., CZ**
  - **ÚTIA AV ČR, Institute of Information Theory and Automation, Academy of Sciences of the Czech Republic**
  - **Jozef Stefan Institute, Ljubljana, Slovenia**
  - **INEA - informatizacija, energetika, avtomatizacija d.o.o., SLO**

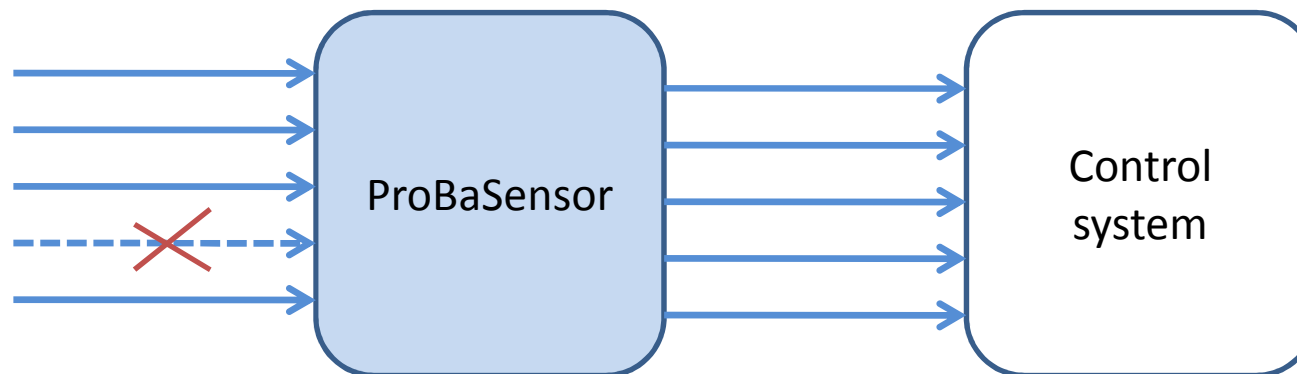
## ProBaSensor Project

- **Main idea:**
  - **In a control system, how to replace a sensor / input signal that is unreliable or even missing**



## ProBaSensor Project

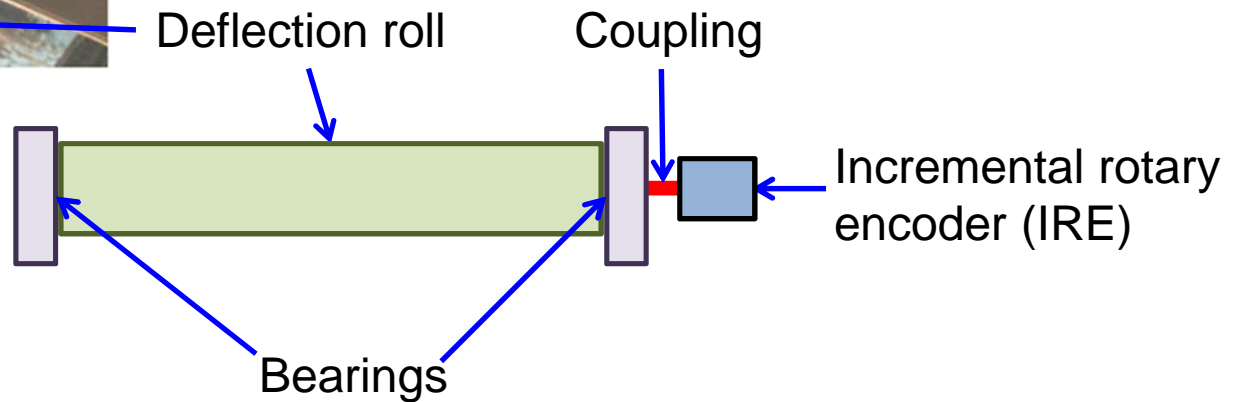
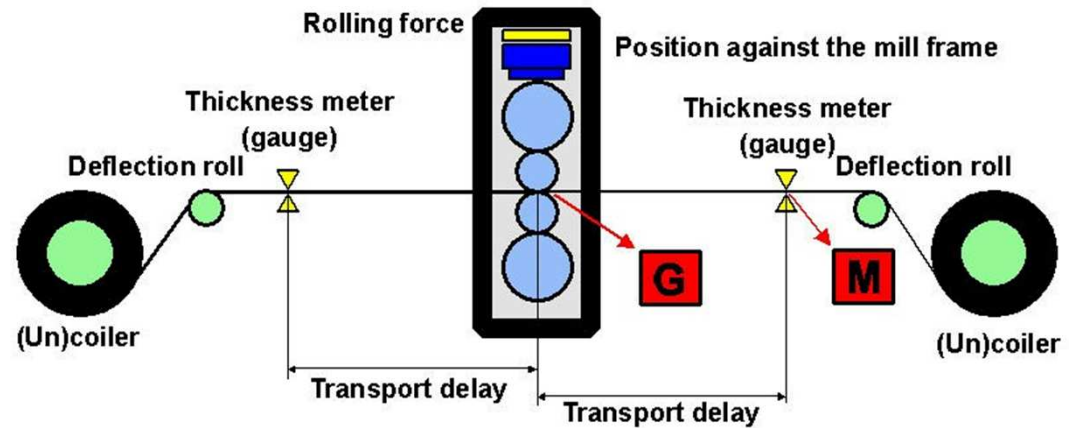
- **Project aim:**
  - To find a way how to **replace / simulate / improve** the **unreliable / missing** signal using the other signals (with high probability)

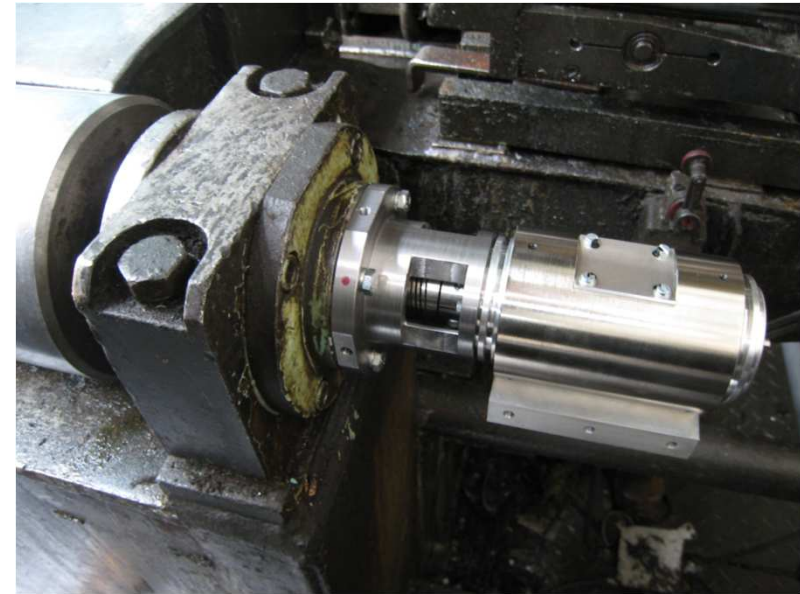


## Speed measurement

- **Precise speed measurement using incremental rotary encoders**
- **Incremental rotary encoders (IREs) are widely used**
- **Applications where even a small error in speed measurement can influence the quality of control substantially**
- **Thickness control of metal strip produced on a cold rolling mill (*mass-flow* algorithm)**

# Strip speed measurement





**Examples of mechanical arrangements**

**Principle of speed measurement:**

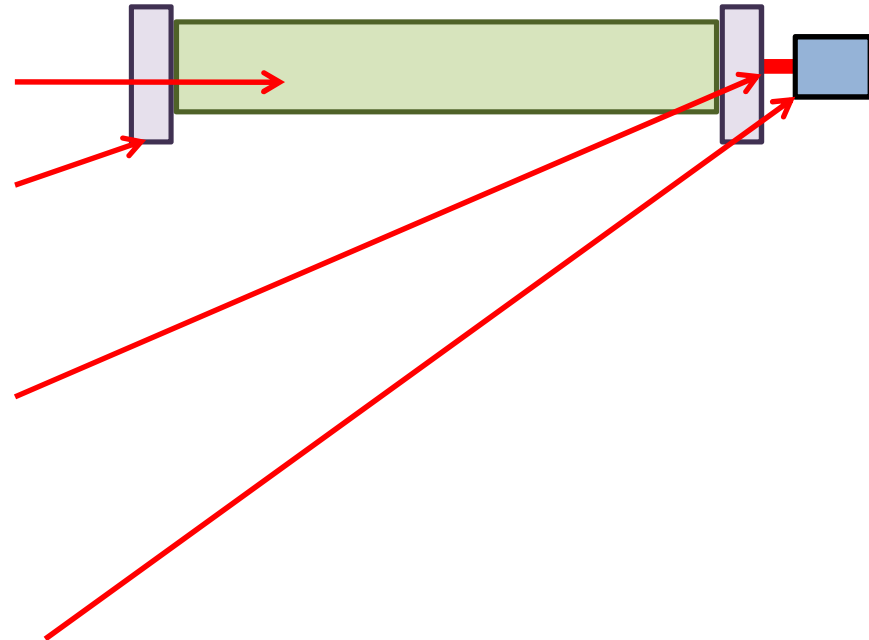
- linear motion transformed to rotation
- angular velocity measured by IRE

## Speed measurement errors

Simple principle x precise values requested

Sources of signal disturbances:

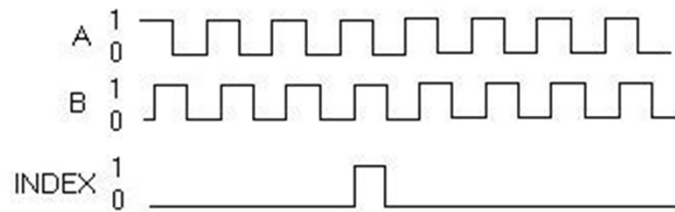
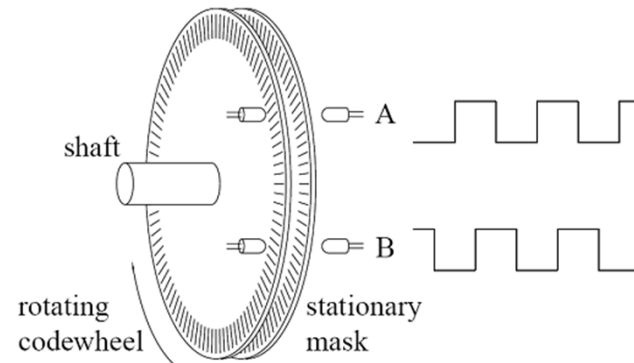
- Roll ovality and eccentricity
  - Imperfect bearings
- Misalignment of roll's and encoder's shafts
  - Imperfect coupling
- **Imperfection of IRE itself**



Types of couplings

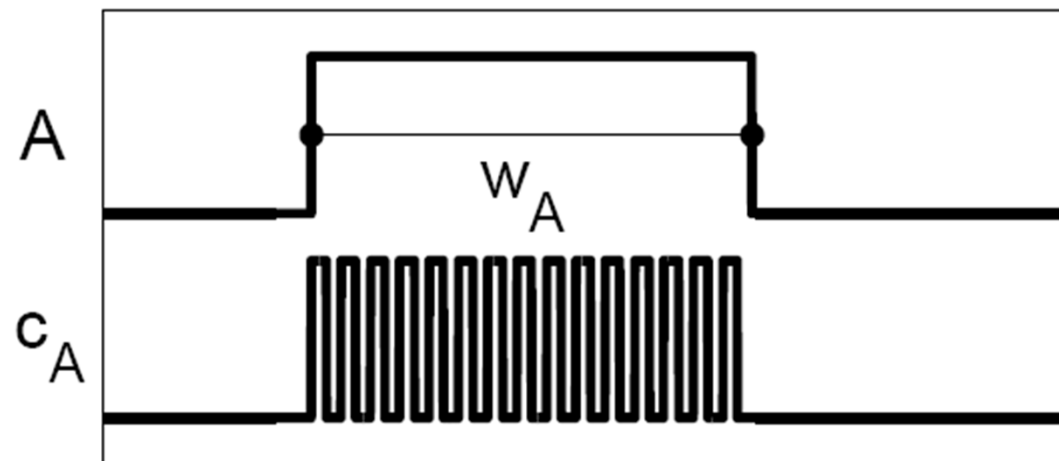


# Incremental rotary encoder (IRE) principle



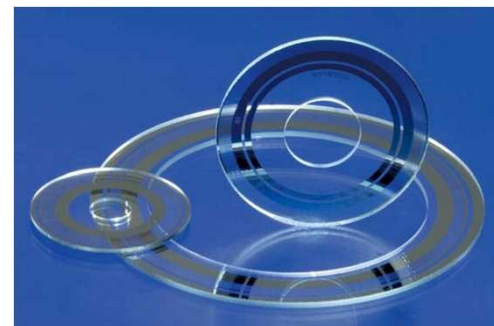
## Angular speed measurement principle

- Measuring the puls width
- Externally generated “fast” pulses
- “Fast” > 1000 times higher frequency



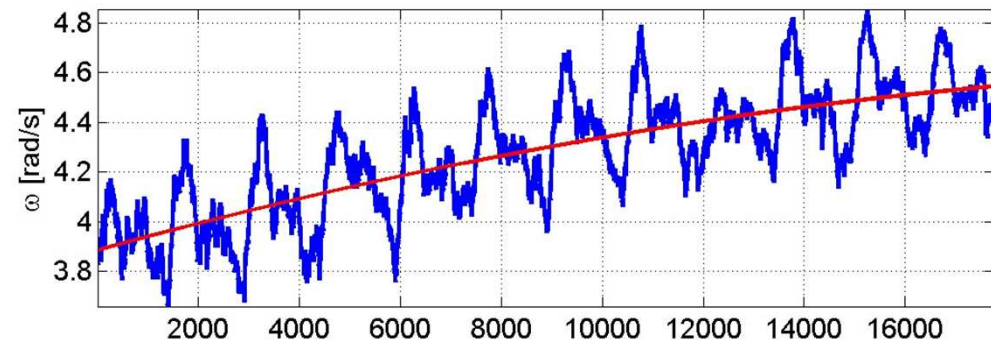
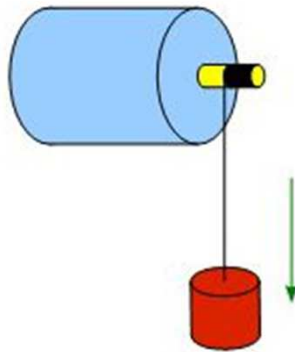
## Inaccuracy of IRE

- Frequency of “fast” pulses high enough → precision ensured?
- Problem: inaccuracy of the graduations on the codewheel
- Width of grading lines typically of tens of microns
- Experiments to examine the character of disturbances
- **Idea: Constant or uniform rotation**



## Initial “gravity” experiment

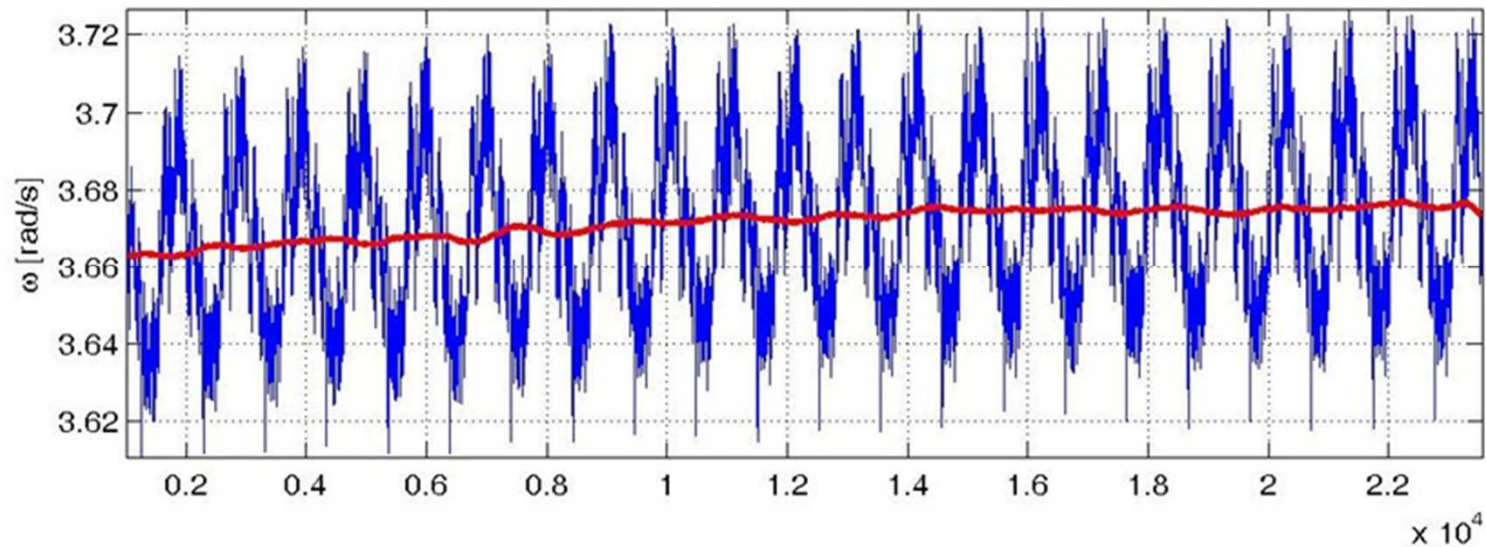
Uniformly accelerated motion, yet periodically disturbed measurement



- Irregular friction of the bearings influences the results substantially
- The sources of disturbances cannot be distinguished
- A turntable like stand with a massive fly wheel constructed
- Good stability and repeatability for further experiments

# Signal filtration

## Experiment with the new stand



- Periodicity → filtration
- Moving average filter – natural solution (time delay)
- Real-time control → time delay minimization, preservation of dynamics

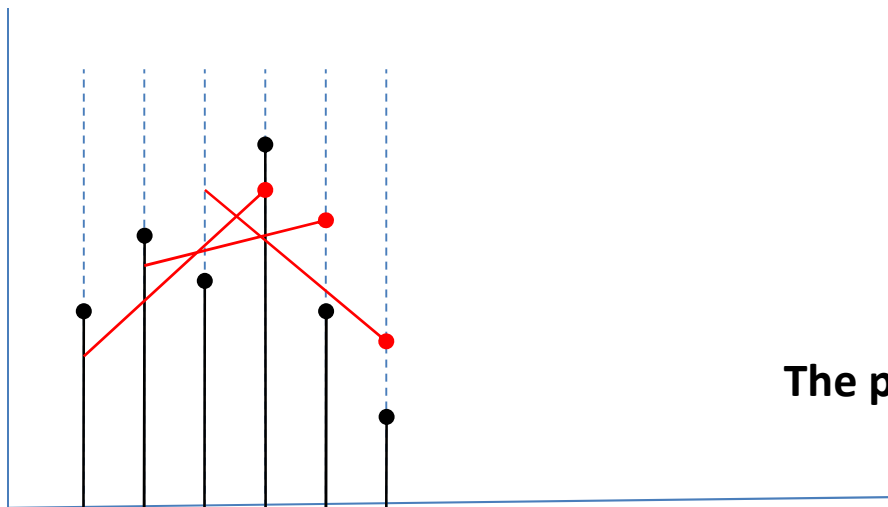
$$\omega_{\text{MA}}(k) = \frac{1}{n} \sum_{i=0}^{n-1} \omega(k - i)$$

n ... number of pulses per revolution

## Signal filtration

Alternative to moving average:

1. Vector of last  $n$  data samples is approximated by a polynomial
2. Polynomial of order 1 – linear fitting
3. Output of the filter = the last point of the linear approximation segment



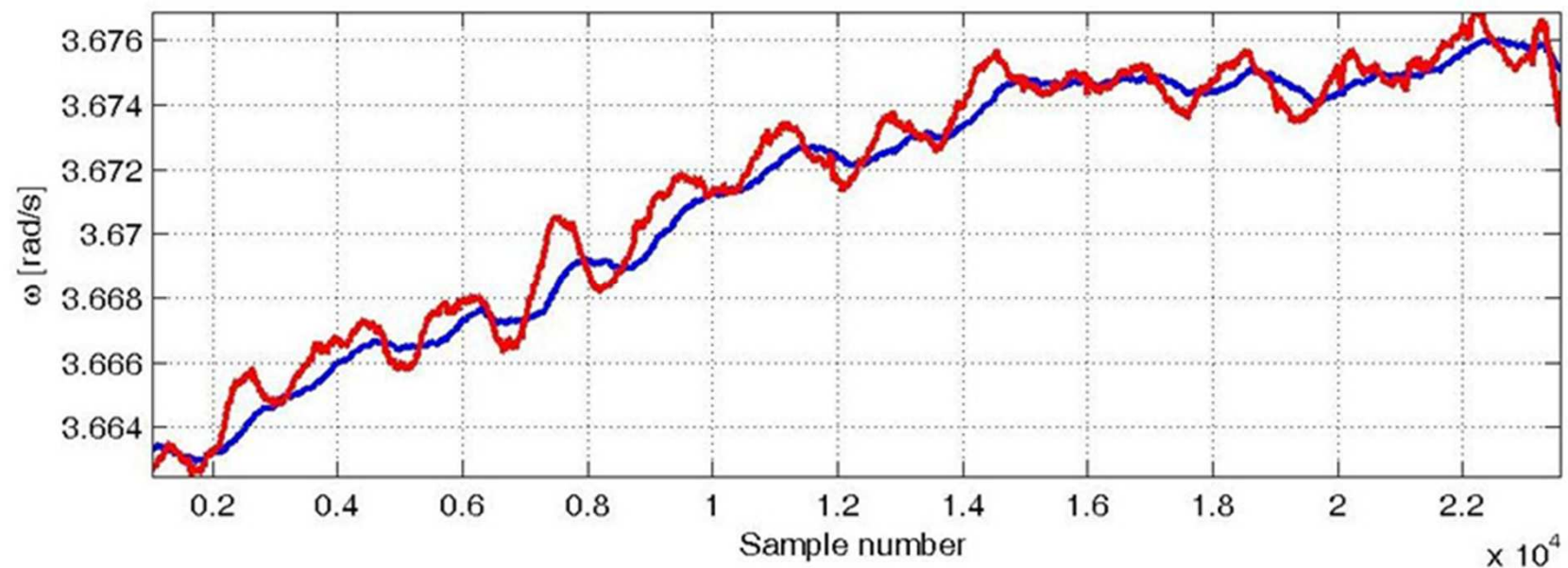
$$\omega_{\text{TP}}(k) = p_1(k)n + p_2(k)$$

The principle for  $n = 4$

## Signal filtration

Trend preserving filter (moving linear fitting) – red line:

- minimal time delay
- better sensitivity to dynamic changes (than moving average – blue line)

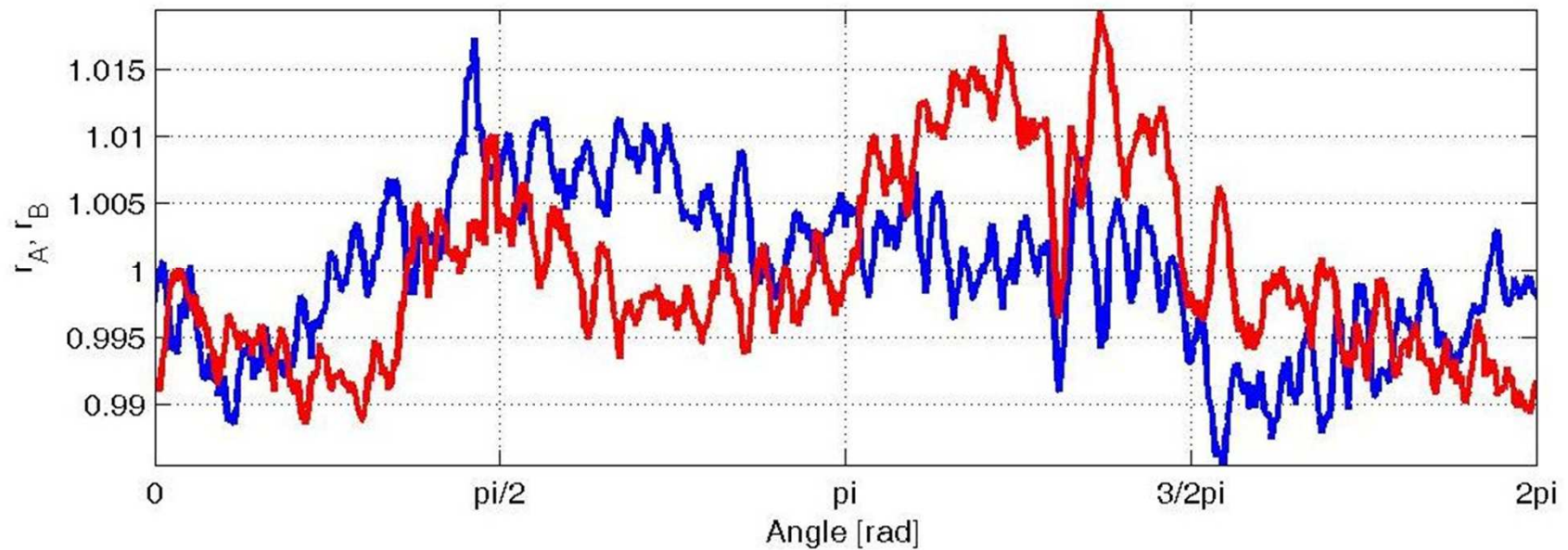


## Deviations of A & B pulses

**New idea:** to use special A & B signal properties for further improvement

- Experiments → A & B signals differ significantly
- Optical detectors have their own grading lines

**Recording of one revolution:**



## Deviations of A & B pulses vs. their ratio

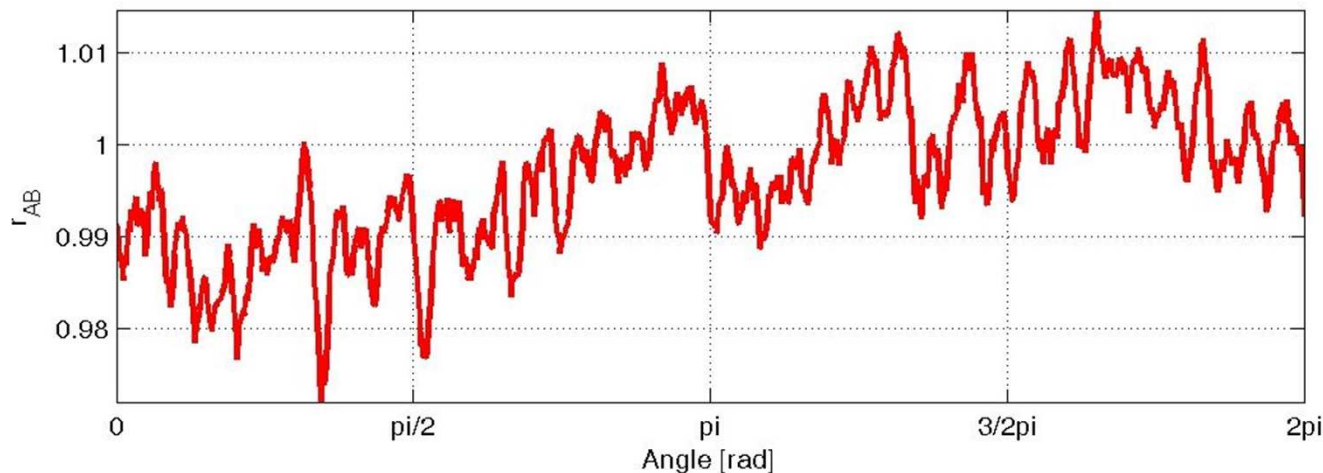
Differences not very promising but the following character found:

1. We index the pulses of one revolution from 1 to n.
2. We name the widths of pulses of A signal as  $w_A(1)$  to  $w_A(n)$
3. We name the widths of pulses of B signal as  $w_B(1)$  to  $w_B(n)$

Then the vector of ratios

$$\left\{ \frac{w_A(1)}{w_B(1)}, \dots, \frac{w_A(n)}{w_B(n)} \right\} = \{r_{AB}(1), \dots, r_{AB}(n)\}$$

is invariant - constant for all revolutions, all speeds.

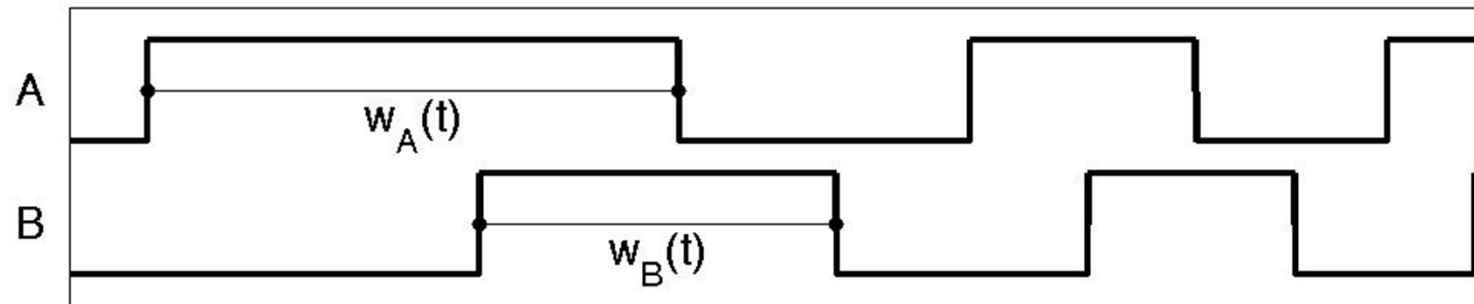


Note: an ideal IRE -  $r_{AB}(k) = 1$  fro all  $\underline{k}$

## Speed signal correction

**Condition: speed is constant during revolution (speed same for A & B measurement)**

**Picture: phase of acceleration**



then actual ratio  $\frac{w_A(k)}{w_B(k)}$

**differs** from that measured at the time of constant speed  $r_{AB}(k)$

## Speed signal correction

**This specific property we will use for the additional correction of the filtered signal**

- 1. Actual increment of velocity is calculated from the difference of ratios**
- 2. Output of the corrector is the output from the previous step with addition of the actual speed increment**
- 3. The trend preserving filter is combined with the corrector**

$$\Delta\omega(k) = \left( \frac{w_A(k)}{w_B(k)} - r_{AB}(j) \right) \Delta t$$

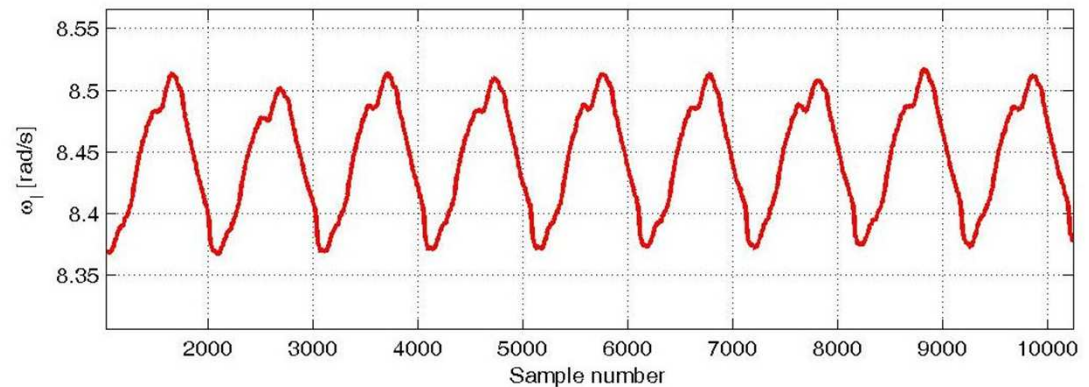
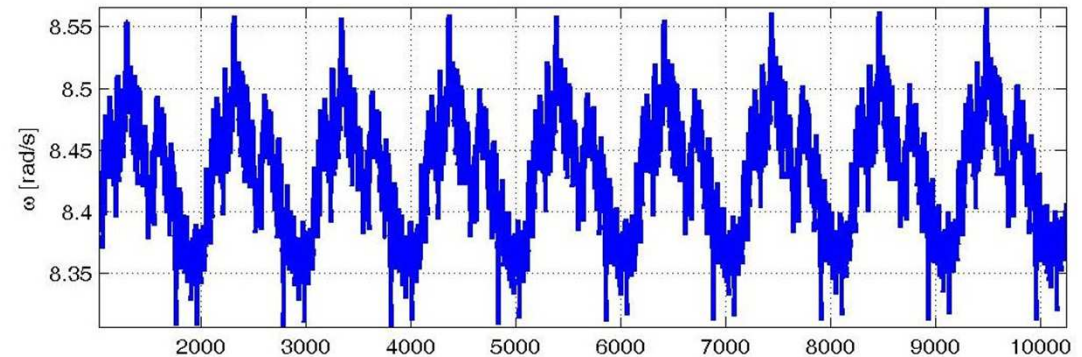
$$\omega_C(k) = \omega_C(k-1) + \Delta\omega(k)$$

$$\omega_I(k) = \omega_{TP}(k) + \omega_C(k)$$

## Example of results I

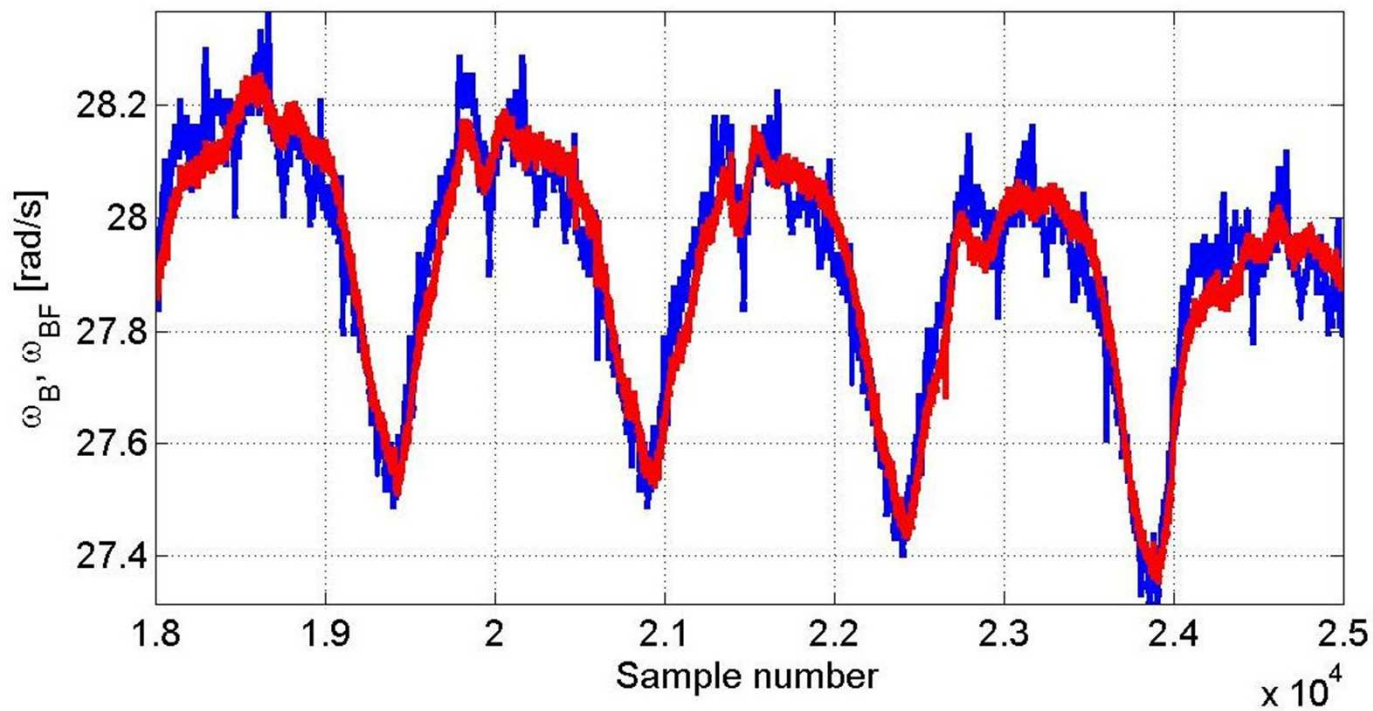
Result of an experiment with the turntable like stand:

- speed fluctuation in the filtered signal ← misalignment of the fly wheel's and the IRE's shafts
- in original signal, fluctuations masked by the irregularities caused by the imperfection of the IRE



## Example of results II

- Raw (blue line) and corrected signal (red line) of angular velocity
- Speed measured on a Ward-Leonard drive system
- IRE irregularities filtered, the other caused by coupling remained



## Conclusion

**Imperfection of IRE is a substantial source of disturbances of the speed measurement.**

**Standard filtering methods cannot be used in case of the strip thickness control on a cold rolling mill (the time delay, frequencies that should be preserved were filtered out).**

**One solution: combination of a trend preserving filter and a corrector based on invariant properties of the IRE.**

**The results are promising but further elaboration is necessary before the real application.**