

New Low-Cost Shapemeter for Smaller Rolling Mills

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While it is true that Shapemeter technology is well developed, and operators of cold strip mills have considerable choice regarding shapemeters on the market, the fact remains that, for the most part, available shapemeters are far too expensive for cold mill operators to afford. A survey of rolling mills currently operating in the world will reveal that the vast majority of mills less than 1 meter wide do not have shapemeters installed.

This is a very sad situation because it is the smaller mills that roll the bulk of the flatness critical light gauges. To make matters worse, it is these light gauges that need to be rolled at higher speed in order to enhance productivity, but, currently have to be rolled at relatively low speed to avoid mill wrecks due to strip breakage. Such strip breaks occur when rolling at faster speeds without shapemeters, because of the natural tendency for the strip edges to tighten when rolling faster due to thermal “puffing” of the work rolls.

In order to achieve a low cost Shapemeter, we decided to apply the following principles:

1. Use a stationary shaft design, enabling direct wiring from transducers mounted on the shaft to external circuitry.
2. Use a PC for control and display purposes, with plug-in expansion boards used for excitation of the transducers and amplification of transducer signals.
3. Use commercial load cells.
4. To keep operating costs down, make the design such that the units can be serviced by a skilled mechanic.

In 1994 we made our first attempt to build a low cost Shapemeter, and supplied two shapemeters to Steel Technologies, Inc. in Canton, MI. These were for 44 in. wide steel strip with speeds up to 1500 FPM. Sensor pitch 60mm.

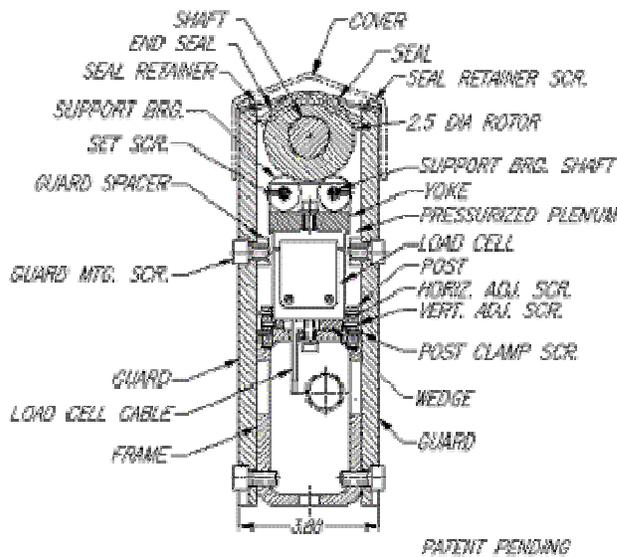
While this design was successful, these units still being in operation today, we did not continue to market it for two prime reasons. These were, firstly, that we felt that the cost was still too high and, secondly, we had concerns about the accuracy of the units at very light gauges.

After more thought, it became apparent that we needed to add three more principles to our list as follows:

5. The physical size of the units should be as small as possible, and the construction should be as simple as possible. Not only does this keep the cost down, but it enables the units to fit existing mills where the space is usually severely restricted.
6. The complete assembly must be retractable so that the need for complicated guards is eliminated, and the entry side shapemeter is not subject to wear.

7. The load cells should be external to the sensing roller, enabling quick and easy replacement of parts.

In 1999 we received an order for two shapemeters designed according to these 7 principles (patent pending) to be delivered with a new ZR 67-32 Z-high mill we were supplying, to Jupiter Aluminum for their plant in Hammond, Indiana (1500 FPM). These units have been operating successfully for two years. Since then we have supplied two shapemeters for Otelineox ZR 23C-26 in Rumania, for a Sendzimir mill rolling stainless steel up to 650mm wide and down to 0.05mm (0.002 in.) thick at speeds up to 2000 FPM. For these units a closed loop flatness control system was supplied by the mill builder (IS). The mill also has Sendzimir flexible shaft backing assemblies (FSBA) with narrow saddle pitch, and also segmented idler roll (SIR) to maximize mill profile adjustability. Several more shapemeters are on order, and most will be in operation by the end of this year.



SECTION A-A FROM FIG. 2

FIG. 1

In figure 1 we show a cross section of the unit. This is typical for any zone of the shapemeter whose side elevation is shown in fig. 2. This unit has 20 zones, each zone including a wedge, adjusting screws, load cell, two support bearings each mounted upon a hollow shaft located in a yoke mounted on the load cell, and a rotor, 2.5" diameter, supported by the two support bearings. A shaft, common to all zones, and supported independently of the rotors, in two bearings, one at each end, passes through all the rotors, and rotates with the rotors as the rotors (or some of them) are driven by the strip. The purpose of the shaft, which is concentric to the rotors, is to transfer the drive from those rotors driven by the strip to those rotors outside the strip

edges, so that the complete assembly rotates as one body. The shaft does not touch the rotors, but means are provided to transfer torque between each rotor and the shaft without radial force transfer.

Figure 2 shows the shapemeter head consisting of all the items in figure 1 (except the cover), together with a guide block at each end, to which frame and guards are bolted, which guides the head up and down on keys which slide in keyways in the mounting brackets at drive and operator sides. These mounting brackets are mounted on the deflector roll bases on each side of the (reversing) mill. The head can be raised and lowered using two hydraulic cylinders. The raised height is determined by the position of the adjustable stop screws. We also provide for a second raised height, which is achieved by using a retractable stop spacer bar, which rests between stop screw and stop plate. This enables us to use two different wrap angle settings, one for running at high tensions, and one for running at light tensions. This enables the unit to maintain high sensitivity and resolution when running at the important light gauges, as well as at heavy gauges.

The construction is very compact, the shapemeter head being only 3.87 in. (98mm) wide including 1/2 in. thick guards, enabling the unit to fit in small spaces, usually between thickness gauge and deflector roll. A cover is used (fig. 2) to protect the unit during mill maintenance work.

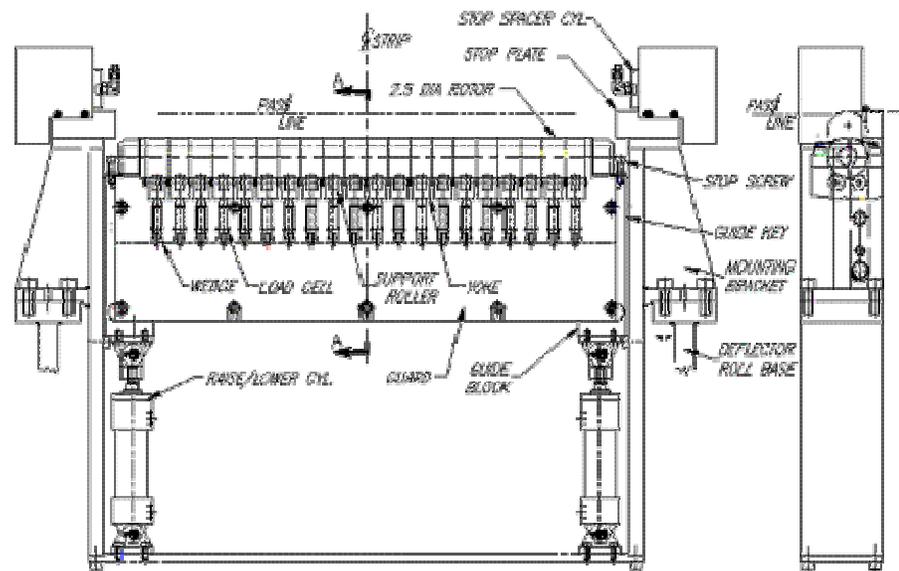


FIG. 2
PATENT PENDING

The shapemeters incorporate several features that are not shown. These include devices to eliminate cross-talk between adjacent measuring zones, and a lubrication system for the support rollers. Also the critical elements are mounted in a pressurized plenum, which prevents entry of rolling oil into the unit. This is necessary because some rolling oils include additives that could attack the encapsulant of the load cell circuitry. Oil used for the lubrication of support rollers (which exhausts into the plenum) is straight mineral oil, with no additives. This can be the base oil of the mill coolant, ensuring that this oil will not contaminate the rolling oil when it exits the shapemeter.

The design of the load cells is critical. Not only must the precision be very high, but also they must be extremely rigid, as any deflection leads to inaccuracies. Furthermore, they need to have positive stop overload protection, the dimensions must be held to close tolerances, and they must be reasonably tolerant of off-center loads. We worked very closely with Sensotec, Inc., of Columbus, Ohio who designed the load cells to our specifications.

Because the shapemeter heads are (relatively) inexpensive it is realistic to keep a spare shapemeter head that can be used to replace a faulty head. In this case the assembly of head together with the cable and terminal board, which are all hard wired together, are disconnected from the remaining wiring (cables to computer and power supply) at the local terminal box adjacent to the shapemeter, and then are replaced with the spare assembly. It's not usually necessary to recalibrate the new assembly, because it can be pre-calibrated, and all that's needed is to replace the calibration file for the removed assembly with that for the new assembly, in the working directory of the Windows PC used for computation and display.

However, no mills have a spare shapemeter yet, because most maintenance procedures can be performed in situ with minimum delays as follows:

1. Replace sensor roller assembly (if a spare is on hand) - 1/2 hour.
2. Remove sensor roller assembly, change a support roller, and replace the assembly- 1/2 hour.
3. Remove sensor roller assembly, change a load cell, adjust load cell (support roller) height and replace the assembly - 2 hours.

The shapemeters can also function with a failed load cell, by using a file which defines the zone(s) having bad load cells. The software reads the file at startup and, for the zone having a bad load cell, the average of the signals from the two adjacent zones is used. Although our experience has been that load cell failures are rare (they do incorporate positive stop overload protection) this feature is useful as it enables a mill to be back in production in minutes after a load cell failure. It's only necessary to edit the file and restart the program, and the mill is back in business. Subsequently, at a convenient time, the load cell can be replaced and the file edited to re-activate the zone.

Other features provided by the shapemeter program are:

1. Manual or automatic zero-ing.
2. Gauge calibration check. With shapemeters of this type where the entire radial force for a zone is measured directly by a load cell, it is possible to use the factory calibrated sensitivity value (mV/V) provided that the amplifications for all the zones are identical. There is no need to have a calibration rig. However, the design does provide for a calibration check using a calibration weight, and the calibration can be easily adjusted, automatically or manually.
3. Smoothing. Because very fast response is not necessary for flatness measurements, the scanned load cell signals are digitally averaged over the desired number of sequential samples, this number usually being in the range of 10-50 samples. This technique is useful at slow to moderate speeds for eliminating cyclic components in the signals caused by minute out of roundness errors in sensor rollers and support rollers. At moderate to high speeds additional smoothing in the time domain is provided by RC lag filters on the amplifier output signals. Such filtering also is needed to eliminate the effect of coil out-of-roundness, such as that caused by gripper hump, upon tension.

In common with other stationary shaft shapemeters it's also necessary to provide for a degree of cross-channel smoothing to compensate for slight irregularities in diameter of sensor roll and

support roll diameters, and slight irregularities in load cell stiffness. This smoothing is restricted to adjacent channels only, and is selectable from zero to 100%. In the case of 100% smoothing the signal from zone n is divided into 3 and shared equally between display channels $n - 1$, n and $n + 1$. We have found that 75% smoothing, where the signal from zone n is shared in the ratio 25:50:25 between channels $n - 1$, n and $n + 1$ respectively, is very effective.

Raw data from the load cells - the program provides for this to be displayed on a separate window when required. This feature has been determined to be very useful for diagnostic purposes.

1. Strip width measurement and strip tracking inputs - the program accepts values of current width and strip offset as delivered from a scanning camera installed on the mill. This feature is used on the Otelinnox shapemeters, where we have seen examples of strip tracking up to 10mm off-center. This phenomenon is very common on light gauge mills. The program has to modify the load cell signals according to the % coverage of the strip on the edge zones, and if the coverage varies as the strip mis-tracks, it's absolutely vital to give accurate strip edge position to the shapemeter, or the display will be invalid, particularly in the strip edge region.

It should be noted that the cross-channel smoothing has to be especially sophisticated in the zones at and close to the strip edges, to avoid transient effects as the strip tracks across the zone boundaries.

2. Coiler wedge effects

The mill at Otelinnox rolls strip which has been slit from 50 in. wide strip produced on a Sendzimir ZR 22B-50 mill. Therefore the incoming strip normally has a complex wedge shaped profile, the difference in thickness from edge to edge being up to 1%.

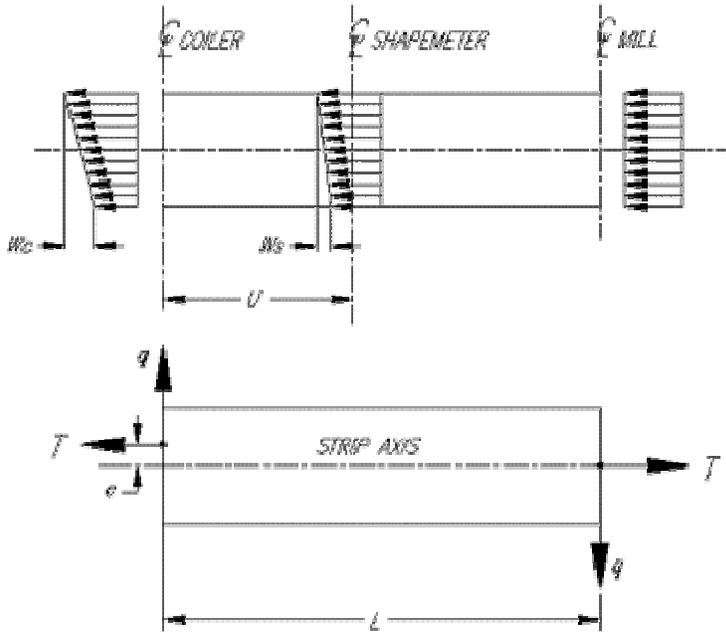
Apart from the ZR 22-32 & ZR 22S-32 mills at Avesta Langshyttan plant in Sweden, we know of no other mills having shapemeters and AFC, so we did not know at startup what problems to expect. In fact, we have found that, as the coil builds up, the shapemeter indicates a gradual increase in wedge component in the tension distribution, even though the mill profile settings are not changed.

Furthermore, if we attempted to eliminate this wedge component by tilting the mill, the amount of tilt required was far higher than the known amount of wedge profile in this strip and was so massive (about 60% of the available range using the mill's crown adjustment system) that it could cause the strip to break.

We found that, if we did not try to eliminate the wedge component of tension distribution, the coil would roll quite satisfactorily. It became apparent to us that the tension distribution at the coiler was not the same as that at the mill, the wedge effect at the coiler not being present at the mill. We believe that the wedge effect at the coiler gradually dissipates along the tensioned band by means of shear stresses, as shown in fig. 3(A). At the shapemeter a wedge component is sensed, which would be 50% of the wedge component at the coiler if shapemeter location were half way between mill and coiler, i. e. if $u = L/2$ then $WS = WC/2$.

This wedge component is superimposed on the normal tension distribution, so that higher order components of flatness error at mill, shapemeter and coil are identical.

Luckily the amount of wedge component of profile in the strip is usually substantially constant from end to end of the coil. Therefore, if the mill can be “leveled” at the start of a pass, i. e. before the coil wedge builds up, and thereafter the mill tilt component frozen, or the wedge component removed from the shapemeter tension signal array, the mill can run perfectly with AFC enabled all the time.



In figure 3(B) we have shown a free body diagram for the stretched band corresponding to fig. 3(A). The total tension at the mill acts along the strip axis at the mill, but is offset a distance e from the strip axis at the coiler. This results in a moment causing shear forces q to develop at mill and coiler, where $q = Te/L$. It is such forces that give the well known tendency for coils of wedge

shaped strip to telescope, and indeed limit the degree of wedge component in the strip for it to be successfully rolled, regardless of the ability of the mill to tilt the rolls to match the wedge shaped profile of the strip. In the presence of these shear forces, it becomes clear that increasing the coefficient of friction between successive wraps of the coil is helpful. Reducing the amount of oil on the strip after rolling and/or using paper interleaf at the coiler, or increasing the surface roughness of the work rolls (and thus the strip) are techniques that can help avoid telescoping of the coils.

7. Coil flatness reports

In the same way that reports of gauge control performance can be generated by storing raw gauge samples on the computer's hard drive during mill operation, and running the report generating program at any subsequent time, similar software is used for the shapemeters.

Scans of I-unit values are written into a report file at roughly 1 second intervals during rolling so that, at any time thereafter, the shapemeter display can be “replayed” and used for several purposes, such as:

- A. Review performance of the AFC
- B. Confirm that specified flatness target(s) for the coil has been achieved.
- C. By e-mailing report files from the mill site to shapemeter and AFC design offices, performance can be continuously reviewed and potential problems diagnosed during the commissioning stages, and also at any future date in order to provide customer support.

Typical flatness display replay is shown in figs. 4, 5 and 6.

Features of the display are:

1. Histogram format, one bar per measuring zone, center zero.
2. Increasing tension causes a bar to raise, reducing tension causes it to lower.
3. Display switchable to show front of shapemeter at right or left.
4. Display shows readout on active shapemeter only (current exit side).
5. Display units are Iunits. Standard range ± 100 Iunits, other ranges optional.
6. Bar widths are scaled according to the amount of strip coverage of the zone. Thus for zones in contact with strip edges, the bar width is reduced according to the partial coverage at these zones.
7. Normal value displayed at each bar is the elongation of the strip in that zone relative to the average elongation of the strip in all zones.
8. When checking calibration, the value displayed at each bar is the elongation in the strip of the notional "calibration gauge" for which the calibration weight is equal to the load cell force which would arise if that strip was elongated by 80 Iunits. Also in calibration mode the value is also displayed as a digital value, for greatest accuracy.

Further possibilities

The stationary shaft shapemeter has an advantage over the classical rotating shaft design, in addition to the advantages of low cost, compact size and simple electronics - because the transducers give continuous output signals, it's possible to sample the signals at a sufficiently high rate so that each transducer is sampled at least once per foot of strip rolled. This enables even transient flatness errors to be detected and flagged.

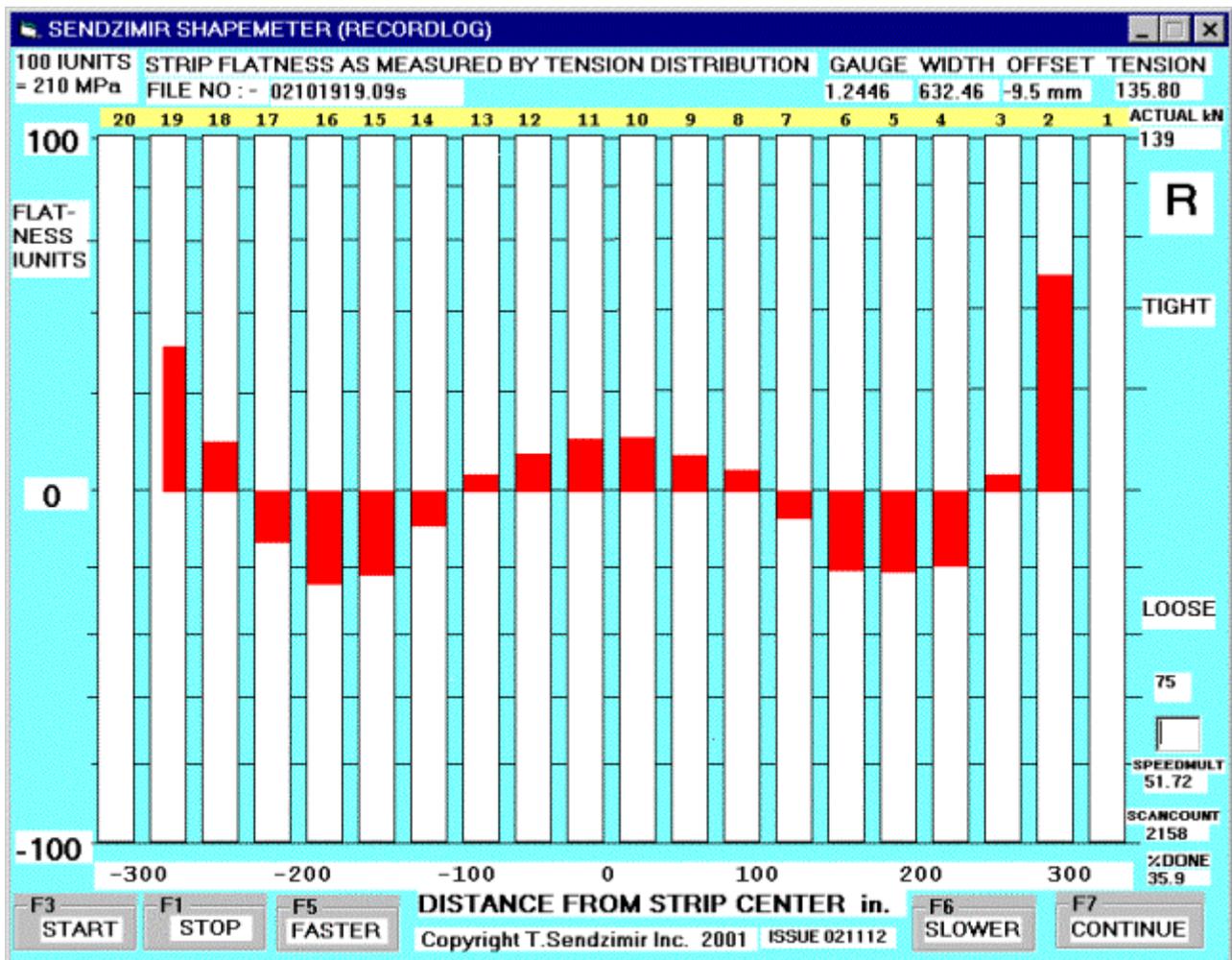
For the first time this gives the possibility of detecting the very dangerous condition of a partial break in the strip, where there is no loss of total tension, thus preventing the very severe mill wrecks which could otherwise occur without warning.

A partial break is one where a crack spreads transversely across the strip, and then turns in an axial direction, (i. e. the crack is L-shaped) creating a piece of strip which readily jams between the rolls causing a pinch, leaving the remaining portion of the width unbroken and thus able to support the tension, thus rendering normal strip break detection (by tension loss) useless.

The feature has not yet been implemented, but is easily done by making relatively minor software changes.

Operating Results

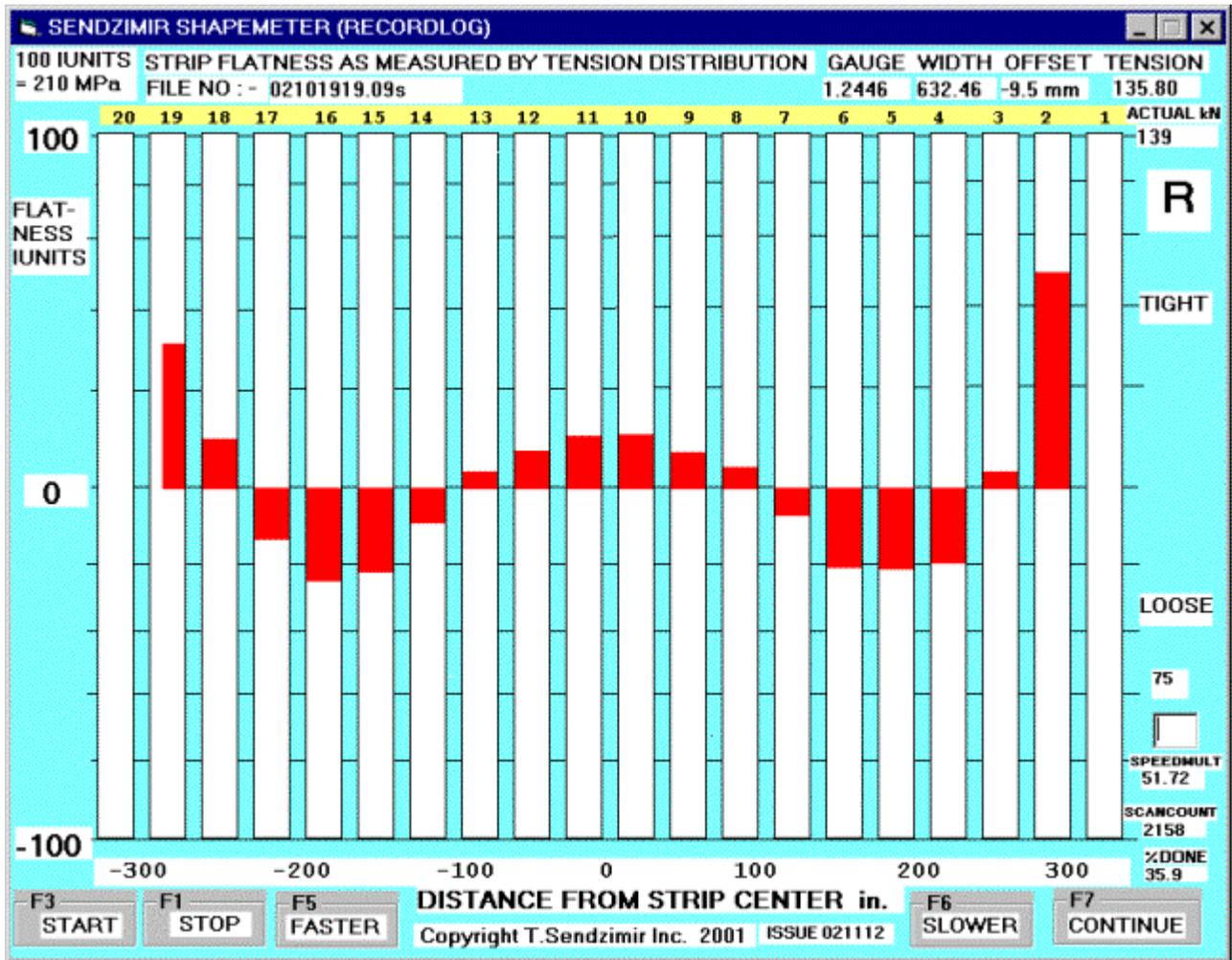
Figure 4



In Figure 4, we show a replay screen showing flatness profile for a coil rolled without AFC. This particular sample was chosen because it illustrates a classical 1/4 buckle shape, which is not unusual. The file name 02101919.09S indicates that the coil was rolled at 19.09 hours on 19th October 2002. The strip was 1.2446mm x 632.46mm wide, and it was being rolled offset 9.5mm towards the front (zone 1 is at the front). Tension was 137 kN, which gives tension stress of 174 N/mm² (25,192 psi) corresponding to an average elongation of 25,192/300 or 84 Iunits. The strip has tight edges, with front edge at 84 + 67 = 151 I units and 1/4 bands at 84 - 25 = 59 Iunits. Thus the elongation is positive across the whole width and thus the flatness errors are latent and thus invisible during rolling.

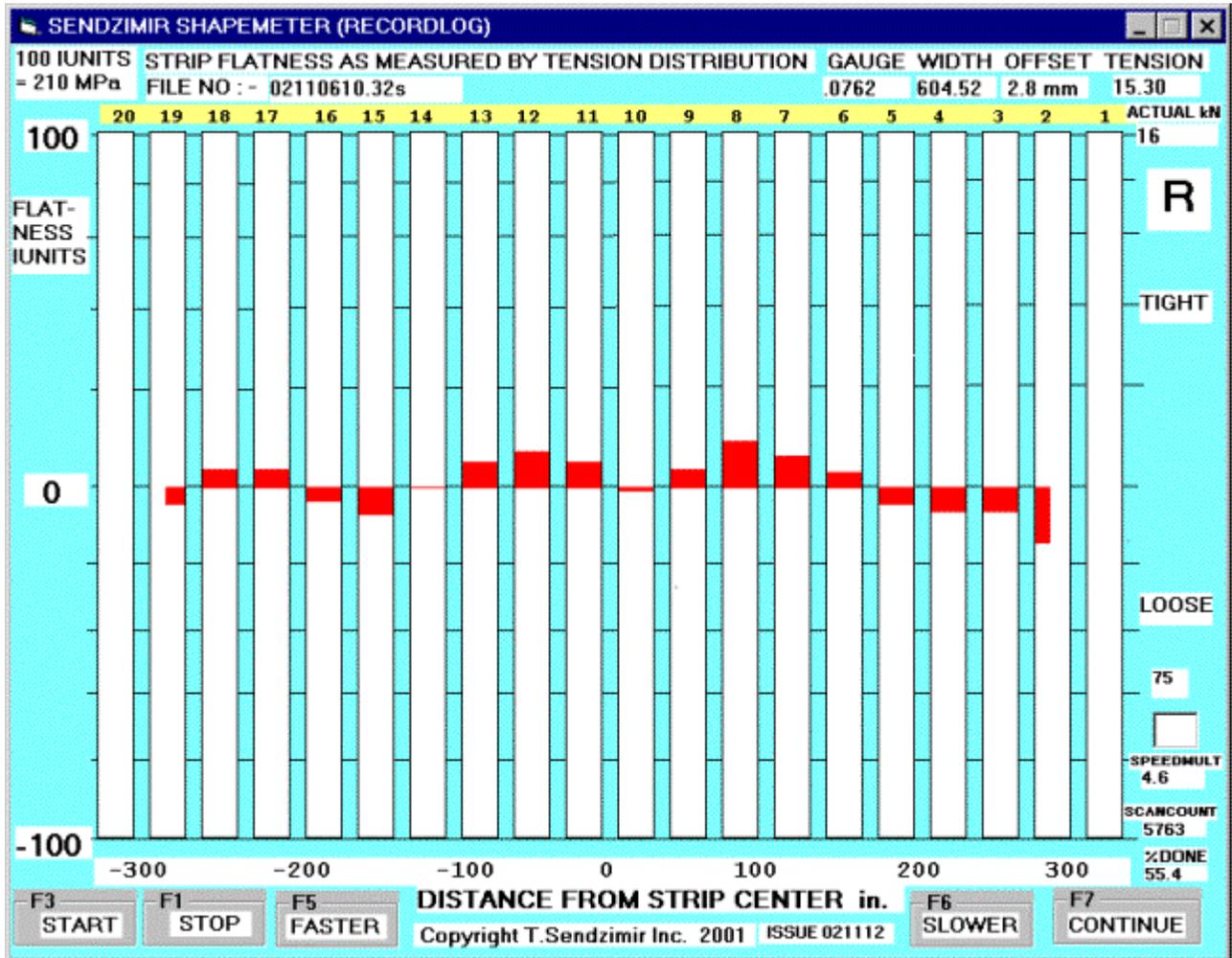
Without AFC, with the operators running the mill, such large deviations from perfect flatness were not unusual. Moreover, we cannot say even that fig. 4 is typical, because a wide variation in flatness profile could be seen among coils rolled.

Figure 5



In figure 5 we show a corresponding flatness profile with AFC functioning, for a coil rolled at 12. 10 hours on 11th November 2002. The strip was .7366mm x 624. 84mm wide, offset 3. 7mm toward the front. Tension was 99N. It can be seen that the flatness is within +/-5 Iunits in all zones.

Figure 6



In figure 6 we show a profile, with AFC for very thin strip. The coil was rolled at 10.32 hours on 6th November 2002 and it was 0.0762mm x 604.52mm wide, offset 2.8mm toward the back. Tension was 16 kN (stress 347 N/mm² = 50,300 psi). Note the edges are properly set a little loose. Accuracy, except for front edge, within ± 7 Iunits.

One of our concerns, when rolling very light gauges in particular, was the possibility of strip marking, and we took extreme care in design and manufacture of the sensor rollers to avoid this.

We are happy to report that no discernible marking occurred.