

# Minnesota Modifications to BPR Roughness Indicator

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During extensive use of the road roughness indicator, built in 1941 from Bureau of Public Roads plans, some modifications of the equipment have proven desirable for the obtaining of consistent and dependable roughness readings. Integrator drive changes and a profile and cumulative tape recorder system have been incorporated. An entirely new integrator built around a commercially available electronic digitizer system is described.

● MINNESOTA'S road roughness indicator was completed and placed in operation in October 1941. It was designed and built on the basis of Bureau of Public Roads plans and specifications revised April, May and June 1941. Operation to date has accumulated over 180,000 miles of travel on two trucks and an estimated 34,000 miles of roughometer recordings. More than 16,000 roughometer recorder miles have been accumulated since 1948. Rivalry among contractors and engineers resulting from its use has been reflected in generally decreasing roughness of new concrete and bituminous paving construction. A low road-roughness index has become so widely sought after since 1946 that it has resulted in increasingly critical interest in operation of the roughometer as well as in construction practices conducive to good riding qualities of road surfaces.

Our use of the roughometer has consisted of the yearly evaluation of construction both as it progresses and following its completion. If the indices reported are to be of value, confidence in them must be maintained. Therefore the use of the road-roughness index as a criterion of roughness requires careful operation of the equipment to assure accuracy and consistency. Furthermore, if comparisons are to be made of the roughness results over a period of years it is necessary to recognize and make proper corrections for the slowly varying responsiveness and freedom of action of the roughometer components.

In view of the wide interest in riding qualities as expressed by the roughness index, modifications of the roughometer which can provide more reliable, positive and generally useful information are desirable. Other additions, which may reduce the necessity for repeat runs due to operator omissions or later need for supplementary information, are likely to reduce the cost of each mile evaluated.

## Difficulties Experienced

Almost all operational procedures were standardized in the Bureau of Public Roads Operations and Maintenance Manual of May 1941. However, some inadequacies became evident soon after routine recording started.

During the final stages of construction of our equipment, wartime priorities made standard size drum-drive cable unavailable. It thus became necessary to substitute an equal length of  $\frac{1}{8}$ -in. drill-rod for most of the required length of drum-drive cable. Tests had indicated that stretch in the available drum-drive cable was appreciably impairing the integrator efficiency within the range of the shorter strokes. Integrator calibration had indicated a fairly constant stroke-length loss but to a lesser extent when drill-rod was used in place of part of the cable. Overcoming the static ball-clutch friction at each stroke causes about 0.003 to 0.005 in. stretch of the cable with resultant loss of motion between the axle and integrator drum. Setting the static position cable anchor out an inch is necessary to avoid bending the cable rod and eliminate the attendant efficiency loss.

Extraneous cumulative roughness counts were observed in October of 1941 while determining roughness index on a smooth-riding road. The occasional registering of two to three inches of roughness in abnormally rapid succession followed by the normal time interval to the next count suggested some cause such as arcing at the cumulative count commutator. Laboratory calibration tests at short stroke confirmed this observation

and a simple over-center snap-action switch was substituted for the commutator in late 1941 to completely eliminate this difficulty.

The construction division in 1942 felt that the roughness index data as manually recorded was deficient in usable detail. Short-interval recording which avoided operator fatigue and error was originally obtained in 1942 by means of an 8 mm camera. This camera automatically recorded simultaneously the two counter readings showing cumulative roughness and wheel revolutions at intervals of 251 feet. This method did isolate roughness variations down to 251-ft sections but still left much to be desired.

A thorough overhaul of the roughness indicator in 1944 brought to light small indentations which had developed in the spring shackle ball-bearing races. Except during World War II when bronze bushings were used, these bearings have been replaced each spring. The effect of these indentations can be felt when the bearing alone is carefully rotated in the hand, and the restraint, though seemingly slight to the touch, very significantly reduces the road roughness index. Double-sealed and shielded New Departure 99504 bearings have been substituted and are now used without the canvas shackle pants, in order to avoid restraint.

Not noticeable when using the original tire of natural rubber in 1941, but distinctly so in later years when using a synthetic tire, was the change in roughness reading after a "warm-up" run. When transported between distant test locations the roughometer is thoroughly secured within the towing vehicle. Observations have shown that any sustained normal load on a standing synthetic tire will result in a flat spot and extraneous roughness in the roughness index. Securing the road roughness indicator within the transporting vehicle with the wheel clear of the floor eliminates the difficulty and is now standard practice.

#### Tape Recorder

A continuous recording of profile and cumulative road roughness characteristics had been desirable for some time. Experience of one of the authors in automatic-pilot operation during 1943-5 suggested a logical basis for such a recorder. In 1947 when equipment became available a tape recorder system was assembled. A two-channel magnetic pen-motor oscillograph continuously records a profile and a cumulative graph readable to a fraction of an inch in roughness. This system makes it simple to automatically record pips at established distance intervals and to manually indicate selected locations as desired.

Information made available by such a cumulative tape record permits detailed analysis of any increment of a roughometer run. Such analysis can segregate variations in roughness resulting from changes in construction practices. Exceptions can be made for readings over bridges, railroads or other non-uniformities which occur during a run. A closely tied-in permanent record of roughness for future reference is thus available with pencilled notes placed on the tape during the roughometer run. Avoiding necessity of re-run due to operator omission in manual recording of the location of a detailed and closely tied-in section in itself makes a tape recorder useful.

Profile records also help to indicate whether roughness is general or localized and to pin-point sections which may be especially smooth or rough. High or low joints and other roughness characteristics can be determined from the oscillograph tape. The profile pattern of bump sequence and their magnitude often indicates why some types of roughness are more objectionable than others. Through experience the character of roughness suggests corrective measures in construction and finishing.

Where no detail is called for and a tape is not required, as in some statewide roughness condition surveys, a warning bell indicating mile points has been found to be of value. Its use has eliminated time-consuming reruns necessitated by operator omissions. This bell is actuated by the same circuit previously mentioned which automatically records the one mile pips when the tape recording device is used.

#### Integrator Calibration

Obvious discrepancies between a high degree of integrator calibration efficiencies and inconsistent roughness indices in the field, led to some changes in 1949. Indications

were that integrator calibration as normally done at a repeated fixed length of stroke is not a true index of integrator efficiency on variable stroke, sequence and magnitude as occurs in the field. We were experiencing considerable spring trouble in the internal drum drive. It was believed that the possibility of internal spring drag at variable length of stroke should be avoided. An external drum-drive spring has been used since that time with a torque increase of about five times.

Integrator calibration should indicate a high efficiency but this in itself is no assurance of a high degree of over-all accuracy. Calibration of individual parts of the entire roughometer has been largely abandoned so long as an over-all check is satisfactory. A selected section of near-by high-type bituminous road having lane markers which can be followed accurately for repeatability has been used for approximately seven years as a standard for calibrating or determining the reliability of the roughness indicator. Another road is occasionally used for double-checking. During the active roughometer season a check on the standard test site is generally made each time the unit returns to the laboratory. The reassurance is simple and rapid and reasonably repeatable, but some type of steel-track check-run would be very desirable.

Frequent interstate comparison of equipment and roughness indices concurrently run on the same roads would be highly desirable. To compare indices between states without such comparison is not realistic. Comparison of spring deflection data, integrator calibration and interchange of integrators, damping cylinders and other parts might do much to standardize equipment, operation and roughness measurements.

There are possibilities of wide variation in roughness results. Such inconsistencies are a function of the operator's alertness to variations in the mechanical condition of the equipment with respect to freedom or restraint of movement during test runs.

Integrator performance over a period of years must certainly vary, but to what extent is debatable and largely unknown. When a simple reassembling of an integrator results in an appreciable calibration change for the better there certainly is reason for concern. Nevertheless there are probably few who can point out where and when repair or replacement are necessary. This was the situation which caused us in 1954 to search for a checking or companion integrator.

### Electronic Integrator

Our present electronic integrator is an adaptation of Telecomputing Corporation's Magnetic Shaft Position Digitizer. The use of this equipment fits commercially available components into a use for which they were specifically made.

Essentially this system divides a cable-drum stroke into minute discrete bits such that they can readily be accumulated by an electronic counter. A radio-frequency, alternating current passes continuously through one winding and magnetically induces an opposite current in a matching winding immediately opposite and facing it. One of these windings is mounted on the stator and one on the rotor of the reading head and are wholly independent of each other mechanically except for a concentric shaft.

Relative motion of the two windings modulates the radio-frequency current which, when returned, to the demodulator, is converted into one discrete pulse for each passing of one winding across the other. Mechanically, the rotor is driven by a cable drum and return spring connected to the roughometer shaft in the same manner as is done with the mechanical integrator. Pulses are produced in both directions and are totaled to indicate the sum of all vertical motion so that identical cumulative indication should be produced by both the mechanical and electronic integrators.

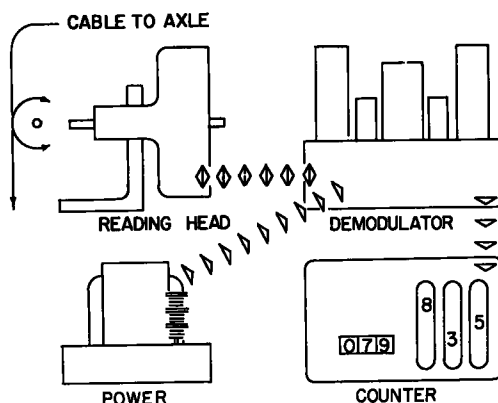


Figure 1. Block diagram of electronic integrator.

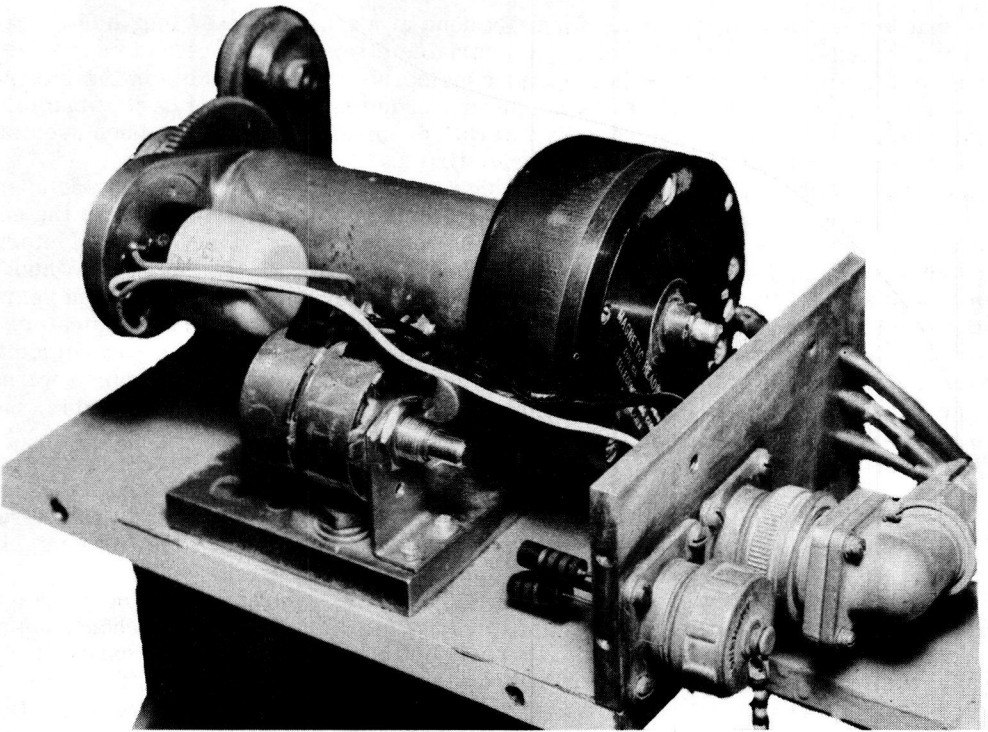


Figure 2. Magnetic reading head.

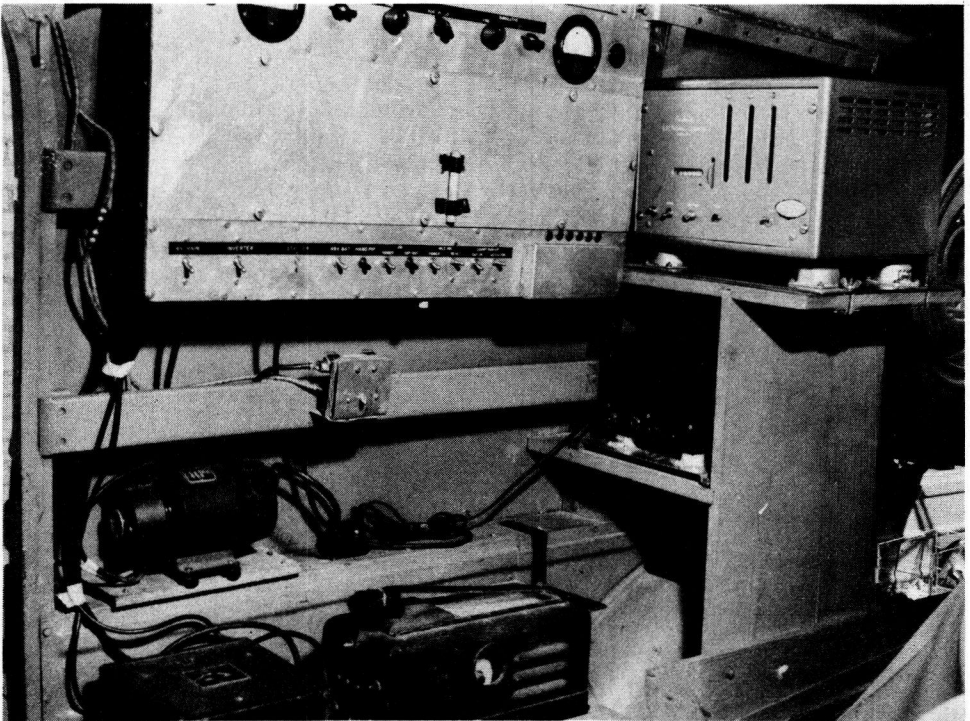


Figure 3. Picture of assembled units as mounted in the body of panel truck.

Four commercially available, electronic units are interconnected to form the integrator and roughness indicating register. These units are shown in the block diagram in Figure 1 and are described as follows:

1. A magnetic, reading head manufactured by Telecomputing Corporation functions to digitize the cable drum rotation. It may be designated as the integrator proper in that it occupies that position on the roughometer. It is mounted in a shop-made cradle which carries the cable drum and profile potentiometer. This is pictured in Figure 2.

2. A small demodulator manufactured by the same company to furnish 1.6 megacycle radio-frequency carrier current to the reading head, demodulate its output and to furnish the resulting pulses, at a rate of up to 60,000 per second, to an electronic counter.

3. A small power supply unit also manufactured by Telecomputing Corporation for the demodulator described above. 110 V AC is required for this unit.

4. An electronic counter manufactured by Berkeley Scientific Corporation accumulates the demodulator output pulses. It has three decimal-counting units and a mechanical register capable of accumulating up to 10,000 pulses per second, random or constant rate. Each thousandth pulse actuates the mechanical register and, a pip on the recording tape previously described, to indicate inches of bump. The assembled units are shown in Figure 3, as mounted within the truck body. The control panel for both the mechanical and electronic integrators is shown in the upper left. The Berkeley counter is pictured in the upper right and the inverter to convert 6V (DC) to 110V (AC) current at the lower left. The power supply and demodulator are mounted on the shelf below the Berkeley counter.

Figure 4 shows both of the integrators mounted on the frame of the roughness indicator.

### Performance

No internal friction, other than in the shaft bearings of the reading head, is encountered in driving the electronic integrator. This eliminates from consideration ball-clutch resistance which probably causes the constant cable stretch loss in the mechanical integrator. The inertia of rotating parts is probably less than one fourth of that in the ball-clutch and other rotating parts in the mechanical integrator. There is no such thing as unaccountable ball-clutch slippage in the electronic unit.

As operated during the past season the cable drum and reading head are so connected as to produce 250 pulses per inch of roughness or deviation from a plane. Additional circuitry is available to increase the pulse rate to 500 or 1,000 per inch of roughness. By appropriate Berkeley counter modifications each pulse rate can be made to indicate inches of roughness directly and record on the tape one pip at each inch of roughness.

With both integrators operating simultaneously from opposite ends of the roughometer axle the electronic integrator index has been consistently higher than the mechanical integrator throughout the past summer.

The average of roughness indices in 1955 of 205 miles of concrete pavement shows the electronic integrator to read an average of 2.4 in. per mile greater than the mechanical. The difference varies normally from two to four inches higher with no consistent

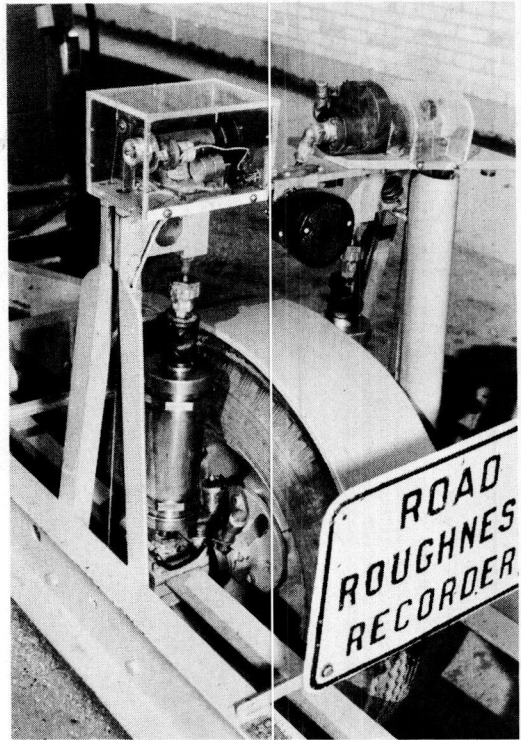


Figure 4. Integrators mounted on roughometer. (Electronic integrator on left, mechanical on right.)

relationship to the magnitude of the index. Recently when differences ranged up to 21 in. per mile the mechanical integrator was brought back into agreement simply by re-assembling.

On the basis of operation to date it is evident that electronic integration can be more consistent and reliable than the mechanical. The equipment is more easily obtained or replaced since commercially available components are used.

#### Maintenance

Maintenance to date has been nil. When needed it is believed that either replacement or commercial repair services should eliminate the necessity of going along with slowly deteriorating equipment where faulty parts or malfunctioning cannot be pinpointed.