Detection of Defect in Steel Sheets Under Coatings by Magnetic Flux Leakage

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Term project report for the course CE 720: Non-Destructive Testing of Materials.

Contents

1 Introduction

Nondestructive techniques like ultrasonic inspection, eddy current testing, x-ray inspection and penetrant testing techniques are widely used for structural integrity of various industrial and civil infrastructure. Each of the method is chosen based on its application and after evaluating the advantages and disadvantages. For example, for the inspection of long pipelines, where the inspection has to be carried out inside the pipelines, ultrasonic and eddy current testing is primarily used [1, 2]. For testing of parts and components of automobiles, penetrant testing is preferred. The devices used in each method have evolved themselves to their applications. Out of these, techniques based on magnetic flux leakage (MFL) have been frequently used for evaluation of defects in structures which are primarily made of steel.

The principle of working of MFL is the same as that in the magnetic powder testing. In magnetic powder testing, the defects are detected when the powder piles up at the cracks and defects due to the leaked flux from the ferromagnetic sample. The high sensitivity and intuitive-ness of this method, it has been successful in being implemented at a large scale throughout the industry that implements NDE [7]– [10]. The simplicity of this method allows the operator without much training to conduct sample tests. Even with these advantages, it carries certain factors that limits the use of this method for several applications. One example being the use of the magnetic powder onto the test sample cause inhibition in the functioning of the test part. It is also quite unrealistic to apply a magnetic powder to an entire stretch of a pipeline.

Limitations like these call upon to the use of something else other than the magnetic powders. With the advent of the semiconductor industry, the availability of the magnetic sensors have been made possible. This allows one to detect magnetic perturbations.
Steel, in all of its forms is widely used in manufacturing and construction industry for decades. Even with the availability of newer materials, steel still continues to dominate as a material of choice for any infrastructure. The large scale use magnifies the challenges that exist for steel as a material. Primarily being that of corrosion – material loss, since after all steel is mostly iron. Mostly the steel primarily used in the industry is carbon steel, which is susceptible to corrosion. As a preventive measure, steel is usually covered in some kind of coating to ensure that there is no part of the steel that is exposed to corrosive forces of environment. Unfortunately the field conditions are such that the environmental forces find a way to corrode the steel underneath the coating. This creates a major problem of having the corrosion defect, or defect of any kind being undetected to any visual inspection.

Be it walls of a pipeline or that of a storage tank, or the steel sheets used in the white goods industries; the defects creep in. Detection methods that currently exists are cost prohibitive. Most medium and small scale industries thus depend on the expertise of the operator [1] for visual inspection, which leads to operator fatigue. Moreover, the process is time-consuming, leading to inefficiency and low productivity. Here I've demonstrated a cost effective device to detect a discontinuity (as a defect) in steel sheets using the very well known method of magnetic flux leakage.

2 Method

Magnetic flux leakage method exploits the phenomenon of perturbation of magnetic flux lines through a ferromagnetic material in the presence of a discontinuity within it [3].
The detection mechanism works in a way where a magnetic field generator (magnet or an electromagnet) creates an uniform magnetic field within the steel (ferromagnetic) sample [4], [5]. If there is any defect present within this sample as shown in Figure 1, the magnetic field lines get disrupted and leak out of the sample. Thus the defect acts like a small magnet. Magnetic particle testing uses this phenomenon for defect detection by spraying magnetic powder on the sample. This method, though useful for many applications is not feasible for the inspection of large scale structure, like pipelines.
The leaked magnetic flux can also be detected if a magnetic field sensor (hall effect based [6]magnetometer) is strategically placed to scan the magnetized sample. These sensors that are strategically placed to detect magnetic fields identify the location of the defect

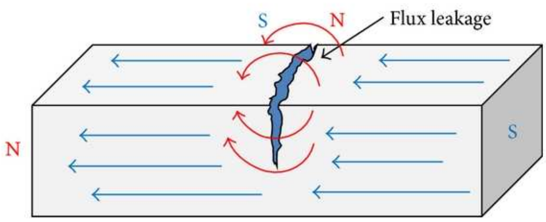
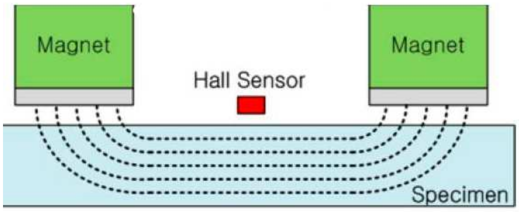


Figure 1: Magnetic Flux Leakage

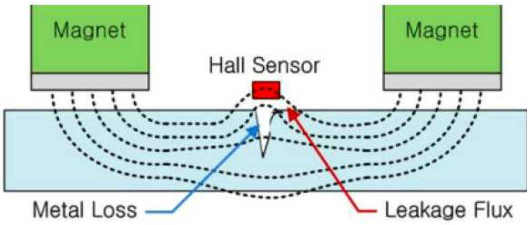
[1]

As shown in Figure 2, the magnetic flux lines flow through the ferromagnetic sample uniformly when no defect is present, but leak out if a defect is present– at the location of the defect. This leaked field is then detected by a sensor. Here

[1]Figures 1 and 2., from: Kim J. W., Park S. NDE. J. Intell. Mater. Syst. Struct. 2017



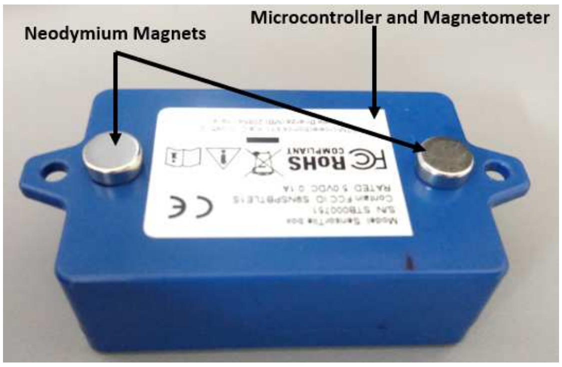
(a) Intact condition



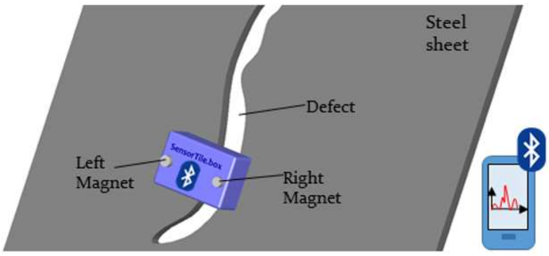
(b) Damaged condition

Figure 2: Detection Method

a hall sensor is used for detection, but several other magnetic sensors – like the GMR, AMR sensors can be used depending on the application's requirements. In this work, a sensitive hall sensor (LIS2MDL) is used which comes inbuilt with the microcontroller - STMicroelectronic's SensorTile.box.



(a)



(b)

Figure 3: (a) Scanning Apparatus, (b) Model of device implementation

3 Experimental

3.1 Test Device

A microcontroller with a built in magnetometer is used as a test apparatus. The built-in magnetometer has a dynamic range of ±50 Gauss and an ability to detect magnetic fields in three axes. This allows the operator the freedom to orient the magnetometer in any direction irrespective of the orientation of the magnetic poles of the magnetic field generator. As shown in the Figure 3a the magnets (Neodymium) are fixed on the top of the device so that they do not cling and stick to the steel surface. The Figure 3b shows the implementation of the device on a steel sheets. The microcontroller is programmed to send the data directly to the phone via Bluetooth. This data is then analyzed for defect detection. The data is also displayed live on the phone. This enables to see the defect while the scanning is being performed.

3.2 Testing

Two carbon steel plates of thickness 1 mm were procured from a kitchen utensils fabricator. The plates were aligned on a flat surface. A electrical discontinuity between the two sheets is measured using a handheld multimeter. Two types of detections are tested. In the first test, the magnetometer is scanned over the plates as the gap length between the plates is varied. In the second test, the gap length is kept fixed and the coating type and thickness is varied. Under no gap condition – where the steel plates are in physical contact with one other and there is no electrical discontinuity between the steel plates. The general scanning procedure is shown in Figure 4.

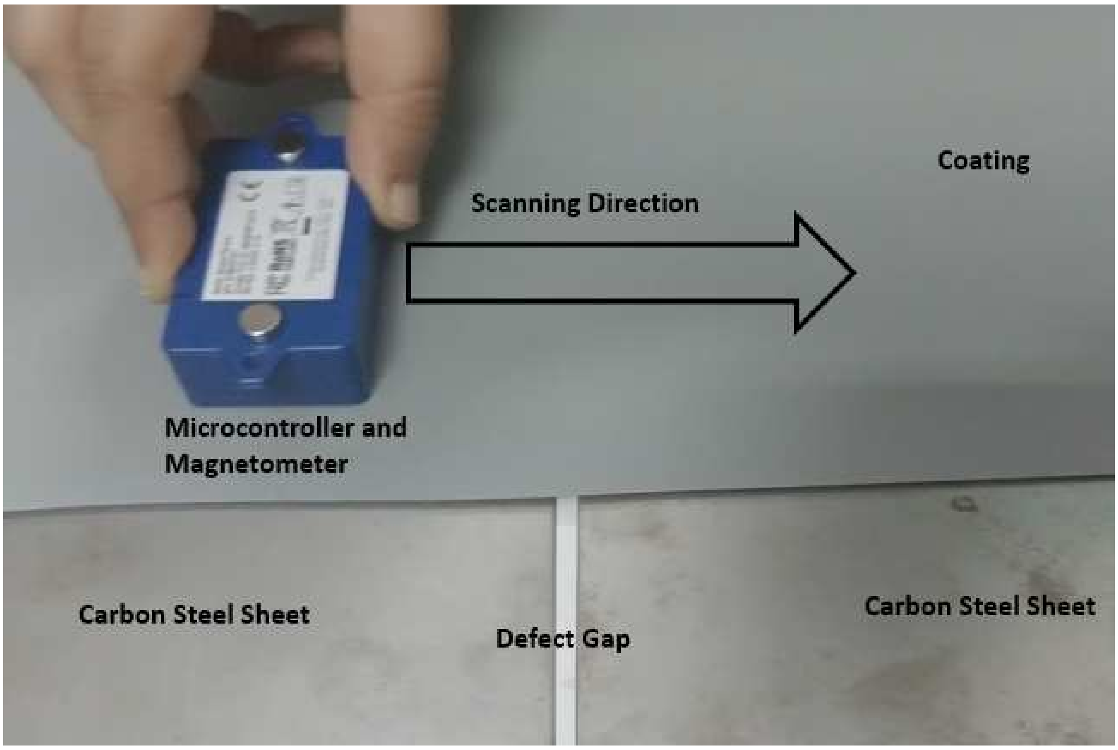


Figure 4: Sample Testing

A simulation in COMSOL is performed to show (Figure 5) that the magnets on device do induce magnetic flux within the steel sheets underneath.

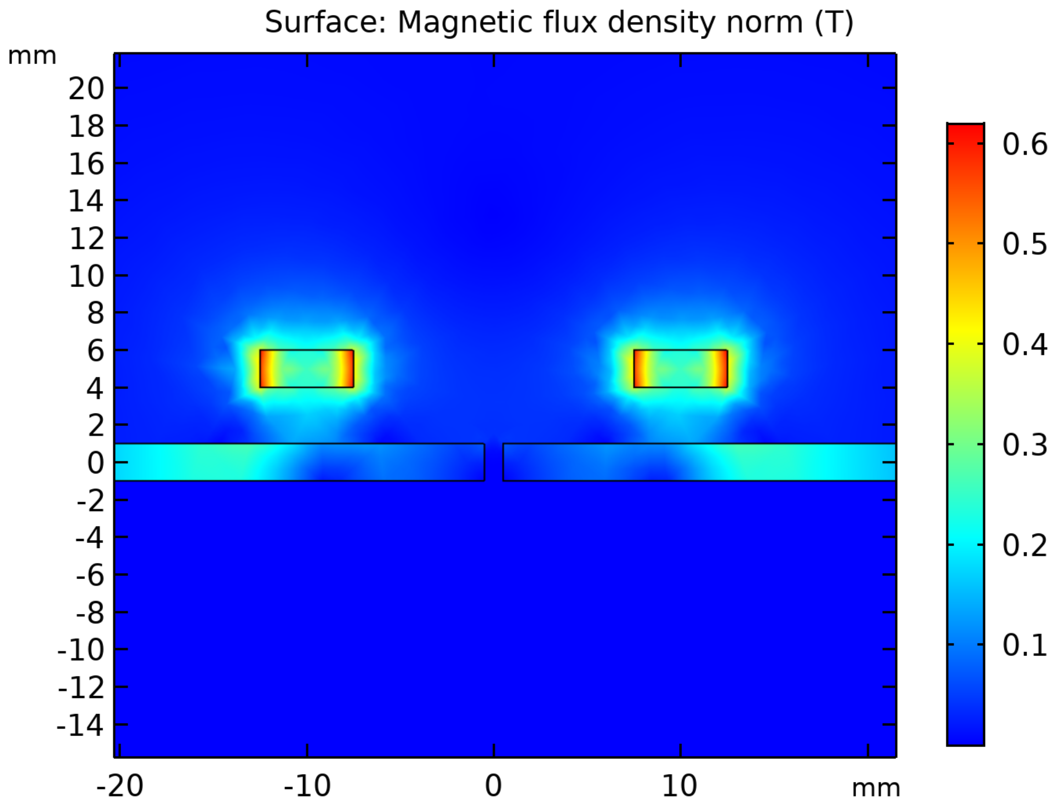


Figure 5: Simulation of magnets over steel plates

The magnetic field is monitored for different gap lengths (Figure 6) and it is seen in Figure 7 that the flux leakage from the larger gaps is larger than for the smaller gaps, though the relation is not linear it is certainly directly proportional – as the defect dimension increases so does the magnetic flux detected by the magnetometer.

Figure 6: Relation between defect size and magnetic flux

In order to get proper data, the scanning speed should be maintained to be minimum. This is dictated by the fact that the sensor can sample data at a limited

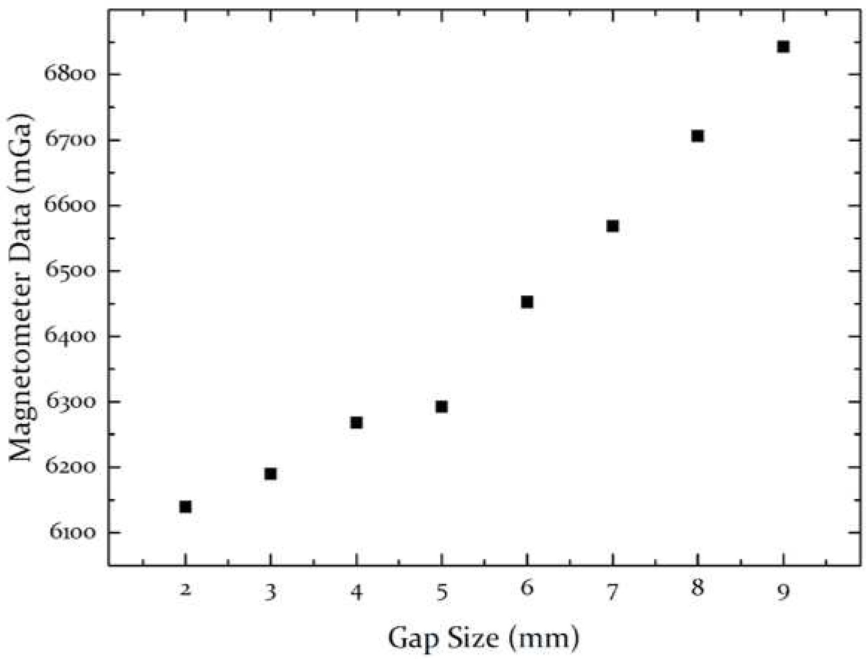
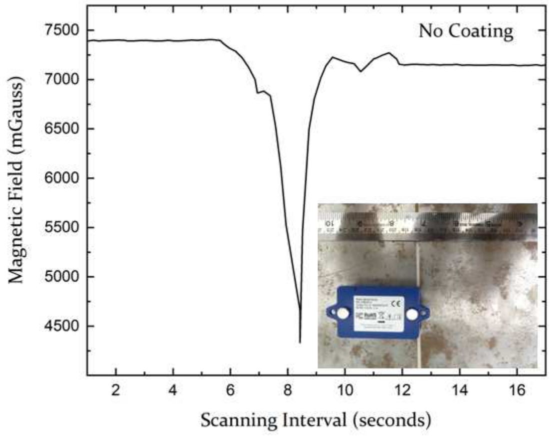


Figure 7: Relation between defect size and magnetic flux

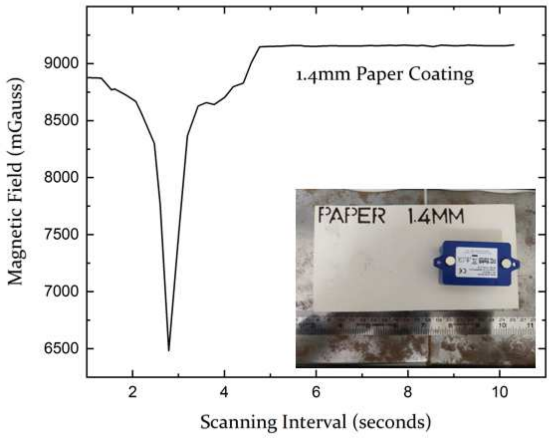
rate (here 2 sample point per second). If the scanning speed exceeds this rate, the chances of the sensor being blind to a defect becomes high.

4 Results

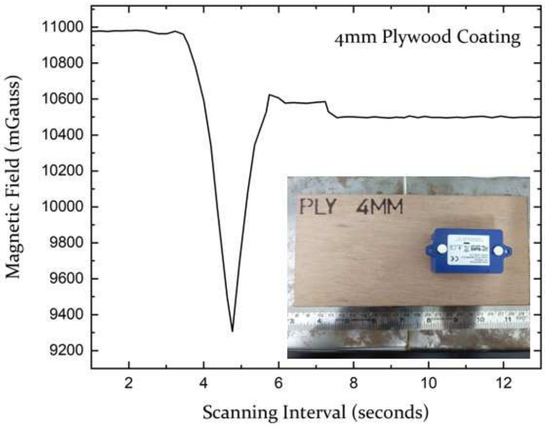
Several coatings where used to analyze the performance of the test device. Coatings of paper, plywood, rubber (in form of a composite) and a dense cardboard is used as the test coatings. The magnetometer data for these coatings is shown in Figure 8. If we compare the Figure 8a and Figure 8c, it can be seen that the magnetometer data for baseline changes a lot. The baseline does not remain constant. Thus the detection of the defect should be made by the absolute change in the magnetometer data for every coating separately without comparing to the case with no coating. To verify if the test device can detect the defect through a coating of multiple stacks of the same material, plywood and rubber coatings were doubled, even tripled in case of the former material. The data is plotted in Figures 9a, 9b, 9c for plywood stacks and rubber stacks. Further, different coatings are added on top of the steel sheets with the defect gap fixed to 3mm. Further to test the detection limit of the device, the coatings were stacked together heterogeneously – mixed stacking of different materials together. The mixed stack of every material stacked



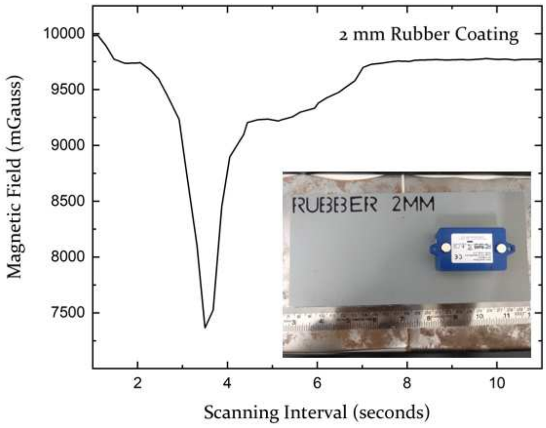
(a) 3mm gap without any coating



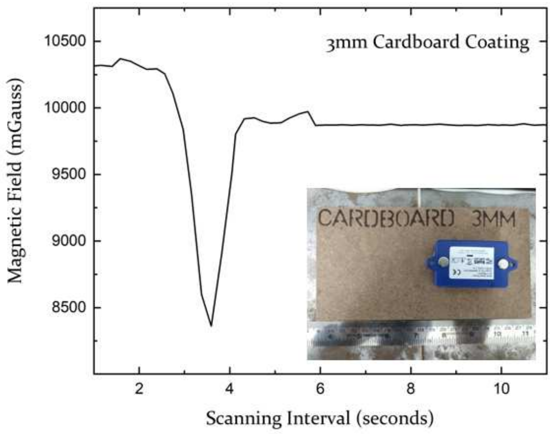
(b) Paper coating of 1.4mm



(c) Plywood coating of 4mm

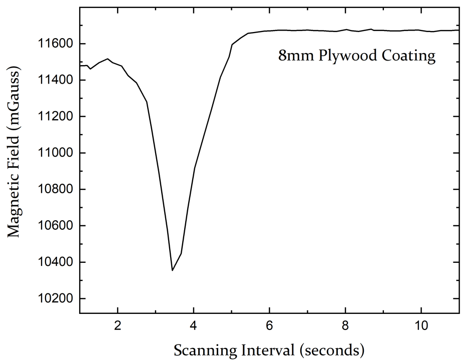


(d) Rubber coating of 2mm

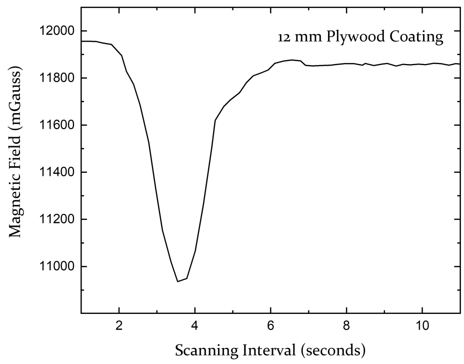


(e) Cardboard coating of 3mm

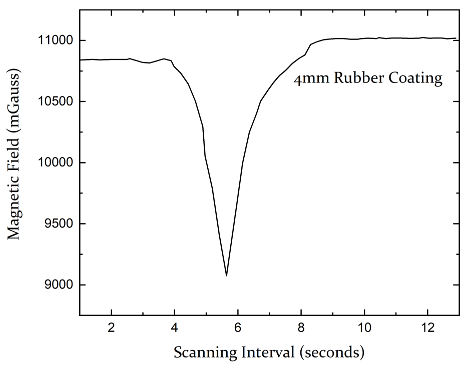
Figure 8: Scan results for various coatings



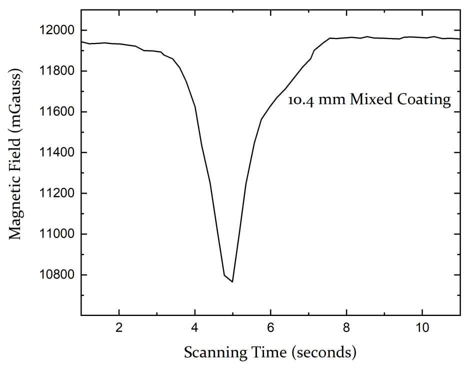
(a) Plywood stack of thickness 8 mm



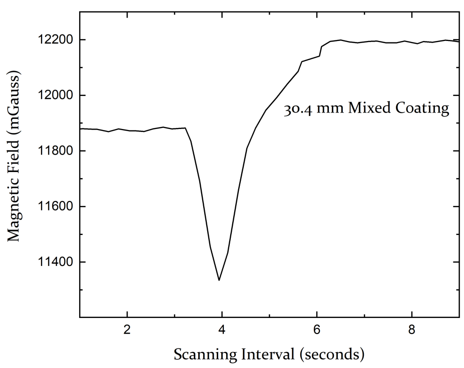
(b) Plywood stack of thickness 12 mm



(c) Rubber stack of thickness 4 mm



(d) Mixed stack of thickness 10.4 mm



(e) Mixed stack of thickness 30.4 mm

Figure 9: Coatings of multiple layered stacks

once resulted in a coating of thickness 10.4mm. Another stack made of all the coatings previously used together resulted in a coating of thickness 30.4mm. The scan results over these two types of coatings are shown in Figures 9d, 9e.

5 Conclusion

Magnetic flux leakage (MFL) is widely used for nondestructive evaluation and testing of structures made of steel. A device that can detect magnetic flux is built by coupling two permanent magnets to a microcontroller which has an builtin magnetometer. This test device is able to detect discontinuity(defect) in a steel sheet. The size of the discontinuity is varied and the response of the device is seen to be directly proportional to it. Further, different stacks of coating materials is applied onto the steel sheet such that defect is under the coatings. The device is able to detect the defect under the coatings of thicknesses varying from 1.4mm to 30.4mm.

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