Magnetic Sensors

Introduction

The Magnetic Sensors developed for the **Blackbrick** are composed essentially of two parts:

- The one sensitive to the Magnetic field, inserted in a 1x1 round brick plus a connection cable to the electronics section of the Black Brick
- The 6x3 mm neodymium Magnet, which is also inserted in a 1x1 round brick

Their function is to limit the travel of any moving mechanism connected to the Lego® Power Function system.

The terms **CW** (clockwise) and **CCW** (counter-clockwise) mentioned in this manual, ALWAYS make reference to the direction of motor rotation (seen from the front, where the output shaft is) which drives the mechanism that the Blackbrick is associated to and NOT to the direction of the mechanism itself.

This can be different from the one of the motor due to a possible gears train interposed between motor and the mechanism, which can change the direction of rotation of the final mechanism itself..

All proposed Magnetic Sensors, regardless of the color of the brick that houses them, can be connected indifferently to **CW** and **CCW** **Blackbrick** ports (see Blackbrick Manual).

Obviously each of the two Sensors will be active only in the direction corresponding to his Blackbrick port (**CW** or **CCW** port) and not on the other.

Remember that the direction of rotation depends exclusively on the commands sent from the battery box (88000, 8881, 8878 ...) or by Infrared Receivers (8884) of the Lego® Power Function system.
The Blackbrick repeats exactly the command sent by one of these devices, respecting the direction of rotation.

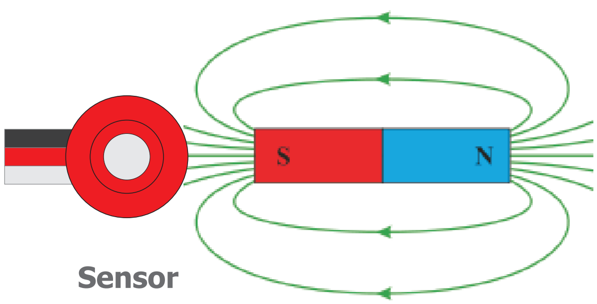
Operation :

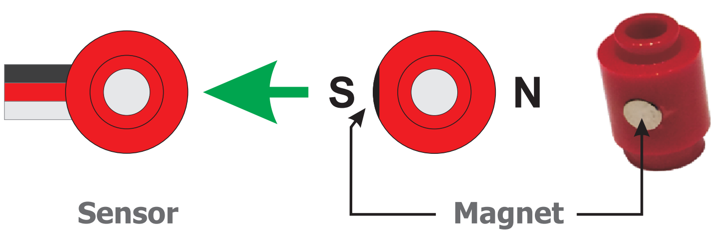
The Magnetic Sensor act as a limit switches with no mechanical parts in contact with the mechanism to control.

They are activated in the presence of a Magnetic field of enough intensity and with correct polarity, stopping the rotation of the motor.

The polarity of the Magnetic field MUST be oriented correctly (Magnetic SOUTH to the Sensor), otherwise the Sensor will be not activated - **Figure 1**.

Figure 1

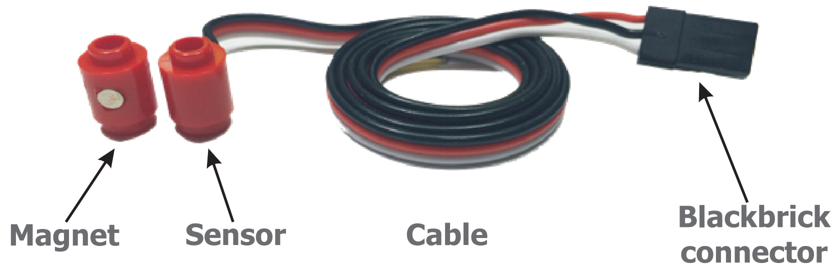




When the Sensor does not "feel" the presence of a correct Magnetic field, it allows (via the Blackbrick) the motor to spin freely, while stops it instantly in the opposite case.

Sensor description :

Figure 2



In **Figure 2** are presented the elements that make a complete Sensor; the connection cable length is about 50 cm.

Installation :

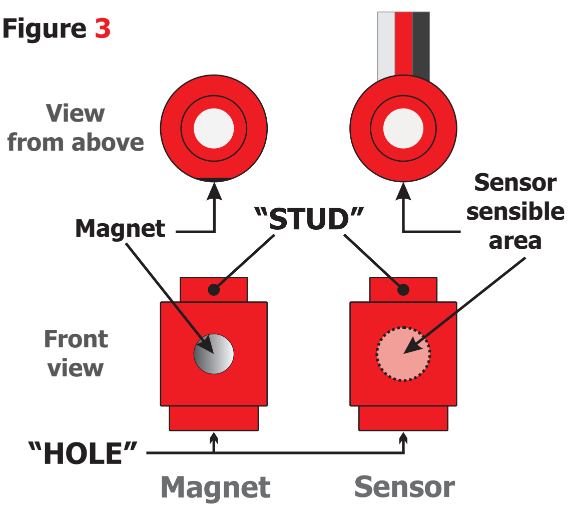
Here followilng will be described some examples and explained the rules for optimum operation of the Sensors.

Being the Sensor and the Magnet encapsulated in a original Lego® 1x1 round brick , will be possible to integrate them perfectly into any building, taking advantage of their typical "jointing" characteristics.

It is important to consider that the Magnet and the Sensor must be mounted on the same vertical (or horizontal) plane on which moves the mechanism to be controlled, so that the sensitive side of the Sensor is aligned with the Magnet in both points of end-stroke.

We will see later how to optimize the position of the Sensor and Magnet to get the desired travel of the controlled mechanism.

Figure 3



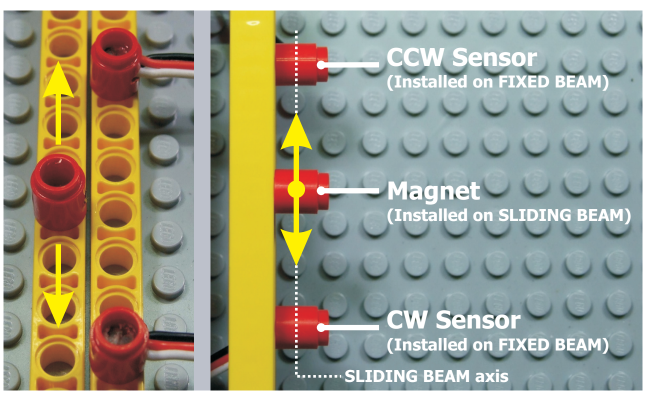
At Left (**Figure 3**) you can understand the main points of the Sensors and Magnets.

In particular, the sensitive area of the Magnetic Sensor which is located on the opposite side of the brick from the zone which comes out the connecting cable.

During testing at the factory the Magnetic field Sensor is calibrated to be at an accurate 180° than the cable outlet hole.

The cable will make the reference for setting the exact angle of the Sensor in respect of the one of the Magnet.

Figure 4

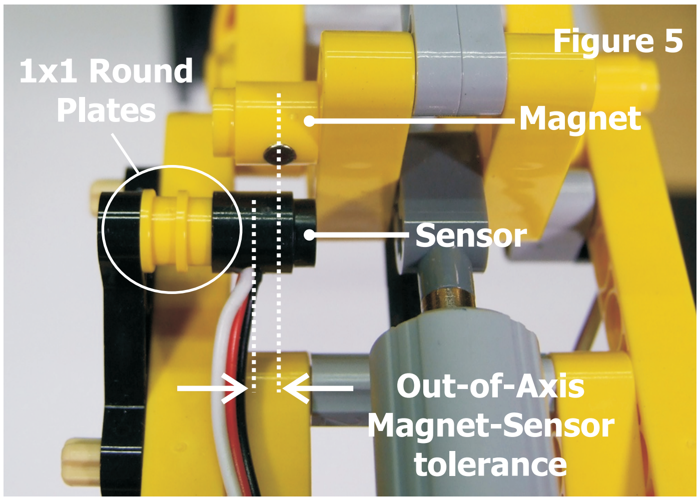


This example (**Figure 4**) represents a situation where we want to limit the movement of a "BEAM" (perforated brick), movable in respect to another, fixed.

Obviously, the mobile one is putted in motion by a motor which will be controlled by Blackbrick, through Sensors.

For simplicity, only one Magnet, which actuates both Sensors, is used; in case it is required a more precise control, you can use two, one per Sensor.

Using the holes of the "BEAM" is possible to vary the position of the Sensors and / or of the Magnet until obtaining the desired stroke of the "BEAM".



In this case (**Figure 5**) the Blackbrick Sensor is used to control the movement of the main arm of the Lego® excavator #8043.

In particular, you can see the couple Magnet-Sensor which controls the end-run of the arm in elevation.

To better align the Magnet to the Sensor, we used two 1x1 round "plates"#85861, as spacers.

As you can see, due to the particular installation, the Magnet assumes an "inverted stud" configuration in respect to the Sensor, causing a Magnetic "off-axis" .

Despite this misalignment, the high sensitivity offered by the Sensor guarantees perfect operations, even for an "off-axis" of **2-3** mm.

Is then quite simply possible to integrate the Sensors in original buildings, using the anchor points provided by the Lego® models structures, with the addition of simple elements and your constructive imagination.

Sensibility :

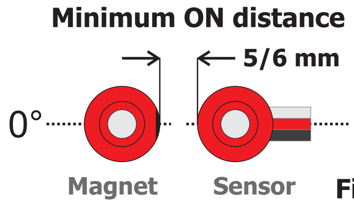


Fig. A

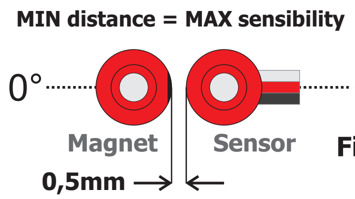


Fig. B

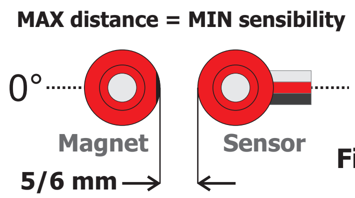


Fig. C

The Magnetic field Sensor has an excellent sensitivity which allows it to be activated also when the Magnet is at a distance of 5/6 mm from its sensitive part.

As shown in **Figure A**, this value is reported to the perfect Sensor axis alignment with the one of the Magnet (0 °).
The stroke of the controlled mechanism will be influenced by the distance between the Magnet and the moving Sensor.

Referring to the example of **Figure 4** at **Page 2**, this distance (which is normally constrained by the arrangement of the mechanical parts of the model) will determine two different behaviors of the system at the end of travel :

Figure B : The Sensor will be activated a **few mm** before reaching the alignment (0 °) with the Magnet, because of its high sensitivity.

Figure C : The Sensor will be activated when it reached the alignment (0 °) with the Magnet.

All the intermediate distances between Sensor and Magnet,from MAX to MIN, will produce premature-from 0° Magnet-to-Sensor alignment, proportional to this distance, how it will be possible to better understand in the next chapters.

Adjustment of Sensors :

As you can see in this chapter, the adjustment of the travel of the movement to be controlled, can be very precisely obtained following different philosophies :

1) Adjusting the Magnet-Sensor position, using the typical coupling methods of the Lego® system, ie the "STUDs" of bricks or the holes of the "BEAMs"

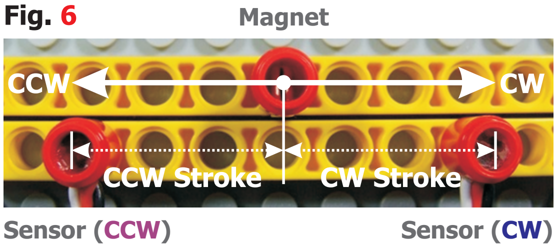
2) Rotating the Sensors and the Magnets in respect of their maximum sensitivity position (0 °)

3) Installing the Sensors and the Magnets on mobile "devices" so you can vary their position

It's possible to exploit at the same time all three types of adjustment described above in order to obtain the desired stroke of the mechanism, in an extremely reliable way.

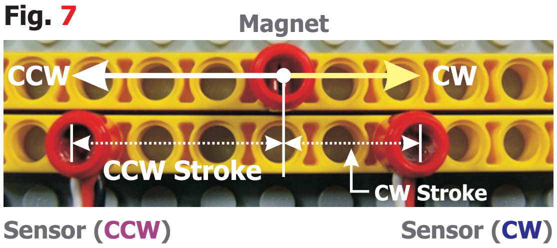
1) Changing Magnet-Sensors position by STUDS and HOLES :

Fig. 6



In **Figure 6** the Magnet has been installed on the top "BEAM", putted in motion by the motor; Sensors on a lower, fixed one, that is part of the model structure. Both are fixed by their "STUDs", inserted in the holes of both "BEAMs". This configuration ensures a "symmetrical" travel in both directions, in respect to the center of the total of the stroke excursion .

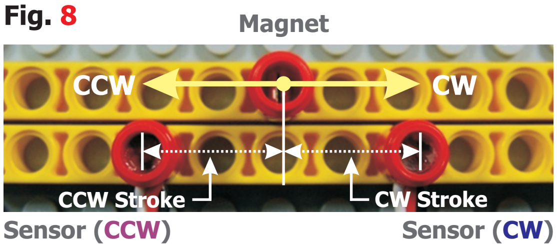
Fig. 7



Moving, as per **Figure 7**, the **CW** Sensor one hole to the left, we will get an "asymmetrical" run , ie the **CW** stroke will be lower than that the one in **CCW** direction.

Is possible, of course, to do the same for the Sensor of the opposite direction, resulting in a reduction of the stroke for the **CCW** direction.

Fig. 8



If it becomes necessary to reduce the stroke of the movement in both directions, simply move the Sensor in the desired locations as per **Figure 8**.

Adjusting the position of the Sensors with respect to the Magnets, using the "joints" of the Lego® system, may not be sufficient to achieve the desired **CW** and **CCW** strokes.

We will use, for this purpose, the methods described below.

2) Rotating Magnet - Sensor axis (OFFSET) :

Fig. 9

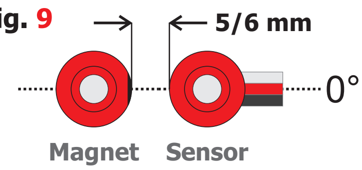


Fig.10

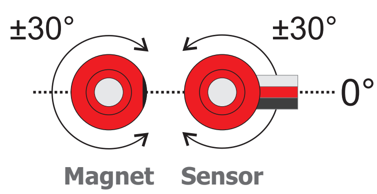


Fig.11

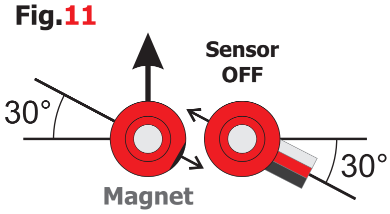
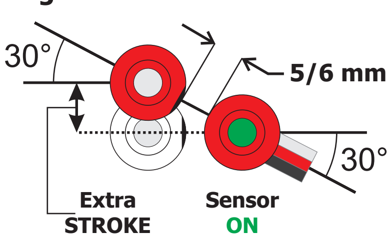


Fig.12



As we have seen in previous chapters, the activation of the Magnet by the Sensor will be in-axis (when both axes are aligned) at the distance of about 5/6 mm - **Figure 9**.

You will hardly find in real life this distance, because of the characteristics of the Lego ® system that make the Sensors and the Magnets (if installed using "STUDs" and holes) are, in fact, much closer, as in the example of **Figure 6,7, 8**.

To reduce (or increase) the stroke to our needs, we simply turn off-axis Magnets and Sensors than it takes to achieve our goal. The maximum rotation possible for both the Sensors and the Magnets is about ± 30 ° from the 0° axis of both - **Figure 10**.

Turning off-axis both Sensor and Magnet, when they will be facing theirselves, don't cause Sensor activation. That's because the Magnetic field emitted by the Magnet is not aligned with the sensitive part of the Sensor.

It is necessary that the Magnet continues in the direction of the arrow (**Figure 11**) because this happens and to get the activation of the Sensor.

The result is that our mechanism has performed a stroke of several mm greater than which would have had if the Magnet and the Sensor were installed on axis (0 °).

In practice, the Sensor is activated at the time when it will be aligned with the Magnet at a distance of 5/6 mm, as shown on Fig.12.

With this "trick" you can cover all the intermediate distances between two "STUDs" or between two holes of Lego® bricks system.

With this example we better clarify how is possible to adjust the end-of-travel by the rotation of the Magnets and Sensors. Two Magnets are used in this case, one for each sense of movement of the upper "BEAM", connected to the motor operated by Blackbrick - **Figure 13**.

This configuration allows to INCREASE the stroke of the upper "BEAM" than the one obtained when the Sensors are "facing" with their "Magnetic axis" aligned at 0°.

The purpose is to obtain an "over-stroke" in case we can't move the Sensors or the Magnets over a certain position, due to the limitations of the "Lego PITCH" or other mechanical restrictions related to the construction of the model.

Fig.13

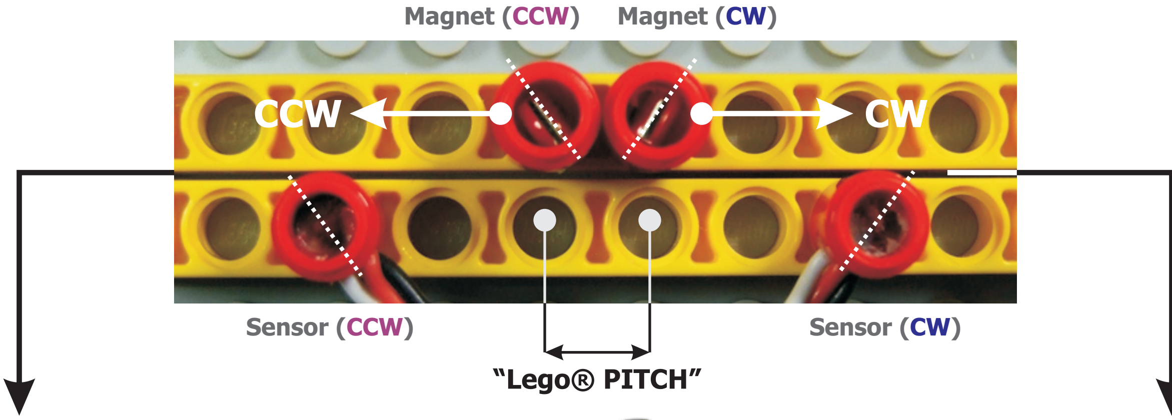


Fig.14

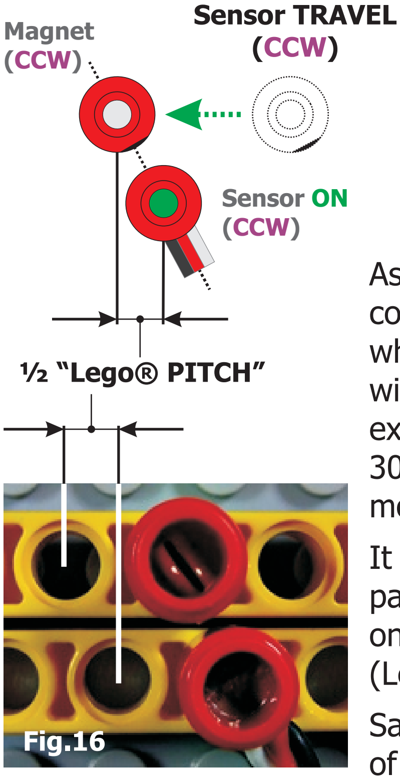
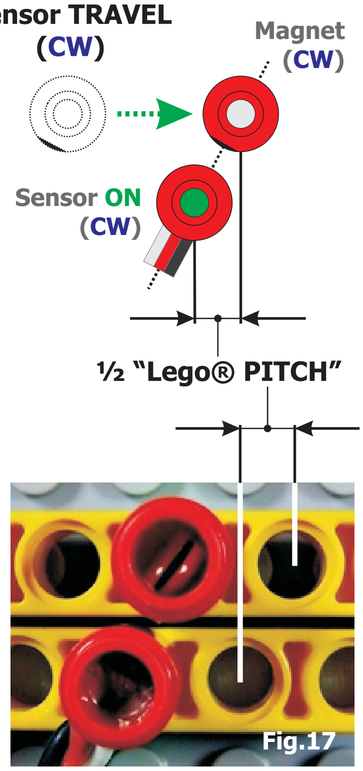


Fig.15



As we can see in **Figure 14** and **16,** relating to the counterclockwise rotation of the motor (**CCW**), when the Magnetic-axis of the Magnet will aligned with the Magnetic-axis of the Sensor (in the example both rotated **counterclockwise** by 30°), the Sensor will activate, stopping the movement of the upper "BEAM".

It can be noted that, upon arrest, the Magnet has passed the Sensor by a distance equal to half of the one existing between two holes of the "BEAM" (Lego Pitch).

Same condition is verified for the reverse direction of rotation (**CW**), as shown in **Figure 15** and **17**.

We overcome the obstacle related to the fixed distance of the Lego® system anchorages that does not allow to position the Sensors and the Magnets in an intermediate position between two "STUDs" of a brick or two holes of a "BEAM".

This distance, called "Lego PITCH", is about 8 mm.

Being able to adjust the off-axis angle of Sensors and Magnets to a total of about 60 degrees, we will be able to cover all end-stroke positions included in "Lego PITCH".

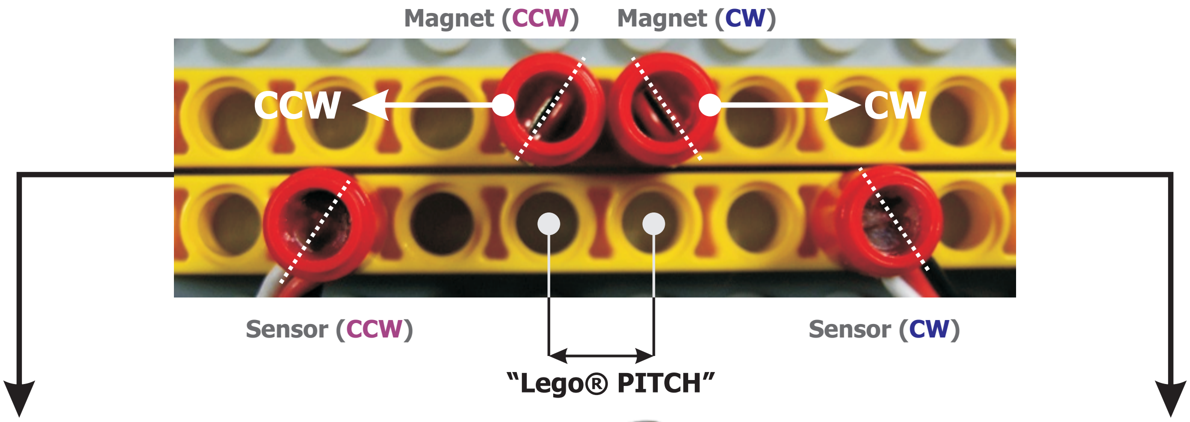
As result we have the ability to very precisely control the stroke of the movement we want to handle.

With this other example we better clarify how is possible to adjust the end-of-travel by the rotation of the Magnets and Sensors. Two Magnets are used also in this case, one for each sense of movement of the upper "BEAM", connected to the motor operated by Blackbrick - **Figure 18**.

This configuration allows to REDUCE the stroke of the upper "BEAM" than the one obtained when the Sensors are "facing", with their "Magnetic axis" aligned at 0°.

The purpose is to obtain an "under-stroke" in case we can't move the Sensors or the Magnets over a certain position, due to the limitations of the "Lego PITCH" or other mechanical restrictions related to the construction of the model.

Fig.18



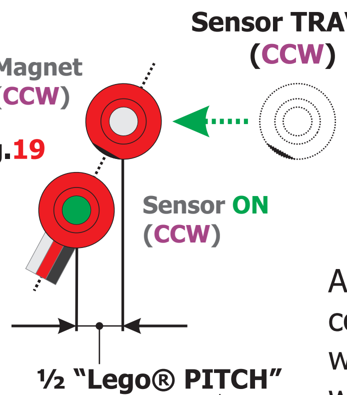


Fig.19

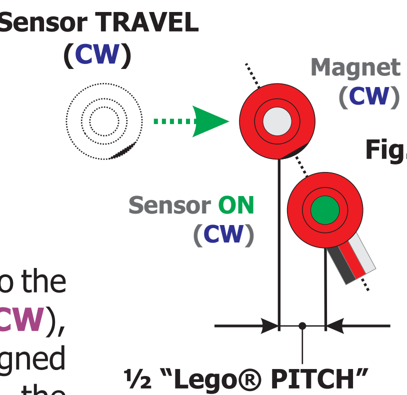


Fig.20

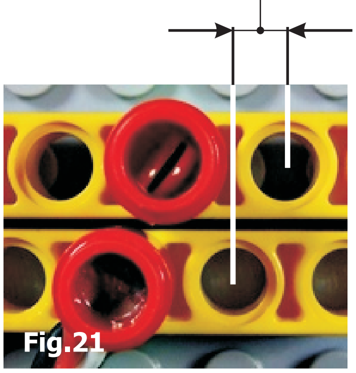


Fig.21

As we can see in **Figure 19** and **21,** relating to the counterclockwise rotation of the motor (**CCW**), when the Magnetic-axis of the Magnet will aligned with the Magnetic-axis of the Sensor (in the example both rotated **clockwise** by 30°), the Sensor will activate, stopping the movement of upper the "BEAM".

It can be noted that, upon arrest, the Magnet has not reached the axis of the Sensor, but it stopped before a distance half of the one existing between two holes of the "BEAM" (Lego Pitch).

Same condition is verified for the reverse direction of rotation (**CW**), as shown in **Figure 20** and **22**.

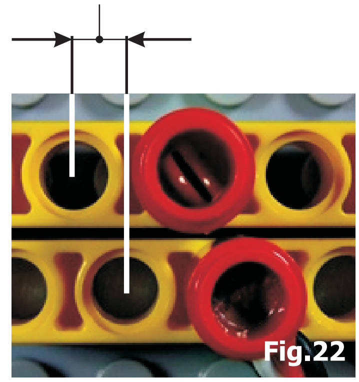


Fig.22

Also in this case we overcome the obstacle related to the fixed distance of the Lego® system anchorages that does not allow to position the Sensors and the Magnets in an intermediate position between two "STUDs" of a brick or two holes of a "BEAM".

It is possible to apply the technique of rotation of the Magnetic axes of Sensors and Magnets in a different way for the two directions of rotation.

This may be necessary in the case we desire, for example, to have a greater stroke in one direction and a minor one in the other.

OFFSET installation example on a Lego® #8043 :

In this section we describe the Sensors and Magnets installation, used to control the movement of the secondary arm of the #8043 excavator, one of the most representative models of Lego Technic ® series.

To don't alter the aesthetic characteristics of the model, truly refined, we don't want to add massive support structures for Sensors and Magnets, limiting them to the minimum necessary to achieve the purpose.

The precise control of the seconday arm excursion (we wanted all the one permitted by the #61927 linear actuator stroke that commands it) was obtained with the technique of the Magnetic-axis rotation of Sensors and Magnets.

Let's analyze in detail the arrangement of the Sensors that control the two senses of rotation, keeping in mind that the terms **CW** (Clockwise) and **CCW** (Counterclockwise direction) are referred to the sense of rotation of the motor which drives the actuator and NOT to the direction of rotation of the arm:

ARM Lowering stroke control - CW

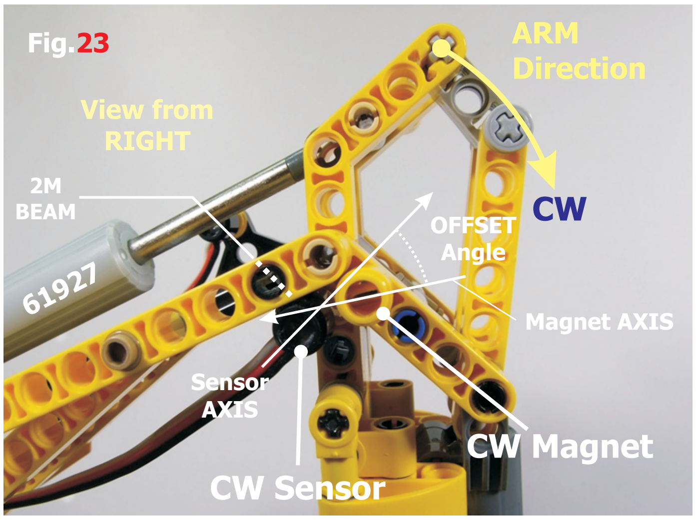
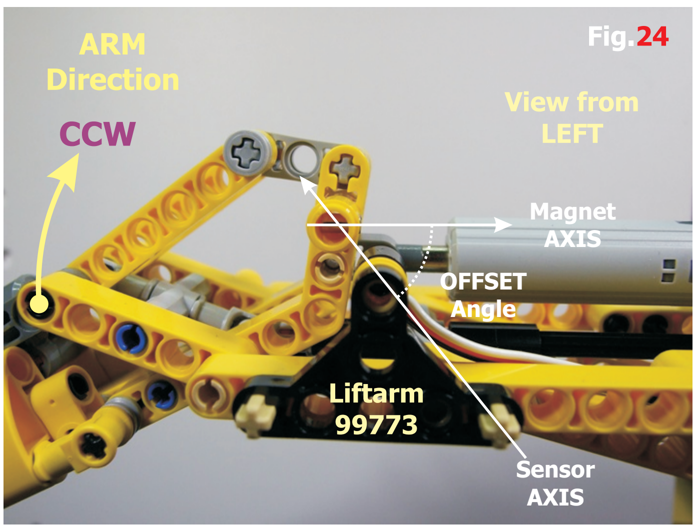


Fig.23 - The **CW** Sensor (black in the photo) has been installed on the right side of the main arm of the excavator, using a 2 holes "BEAM" which allows a minimum of forward and backward moving of the Sensor itself.

This adjustment wasn't enough to achieve the desired travel, as the great sensitivity of the Sensor made him turn ON much earlier than the real mechanical end-stroke of the secondary arm.

We decided to virtually decrease the sensitivity of the Sensor by increasing both Magnet and Sensor Magnetic off-axis (OFFSET Angle).

ARM Elevation stroke control - CCW



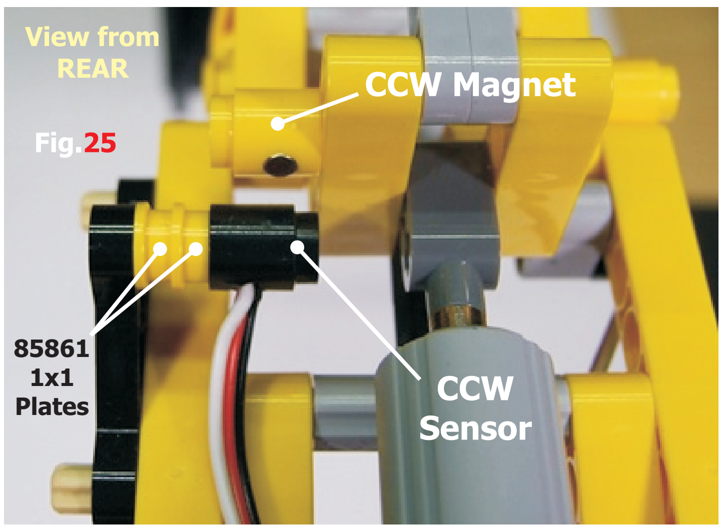


Figure 24 e **25** - The **CCW** Sensor (black in the photo) has been installed, via a "LIFTARM" #9973 and two 1x1 round "PLATES" #85861 (as spacers, to align it with the Magnet), on the left side of the main arm of the excavator..

The Magnet is directly attached to the movable structure of the secondary arm, using his "STUD".

Even in this case, always due to the very high sensitivity of the Sensor, it was necessary to estabilish a strong OFFSET Angle between Sensor and Magnet to reach the total stroke of the secondary arm.

3) Adjusting Magnet-to-Sensor position :

Another solution to optimize the stroke of a moving mechanism is to install the Sensors and the Magnets on a moving part, being able to adjust their absolute position.

This one is the solution adopted on the #8043 excavator used for the precedent example, where both Sensors that control the stroke of the main arm ("BOOM") were installed on a 5-holes "BEAM" set in place on the model frame on one end, then free to rotate on the coupling point.

Fig.26

To install the 5-holes "BEAMs", supporting the Sensors, to the excavator frame, #2780 "friction-connectors" has been used to provide some resistance to rotation of the "BEAM" itself, in order to prevent undesirable displacements of the Sensor, once found the correct position - **Fig.26**.

Fig.27

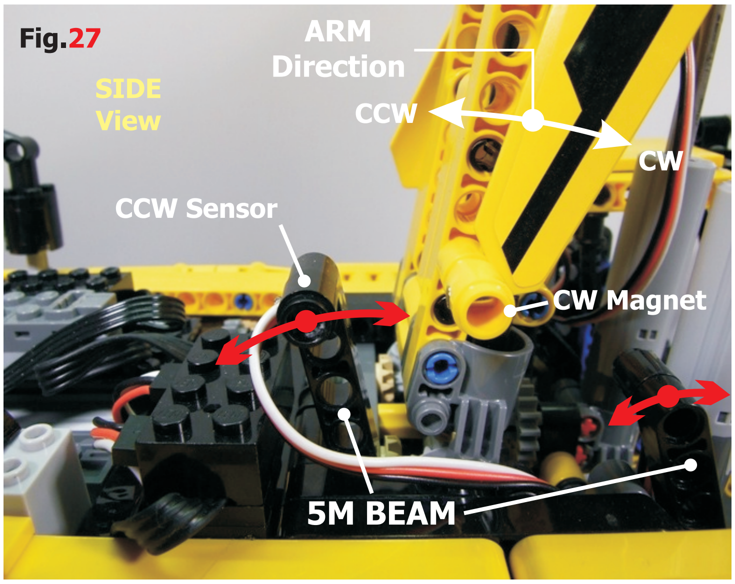
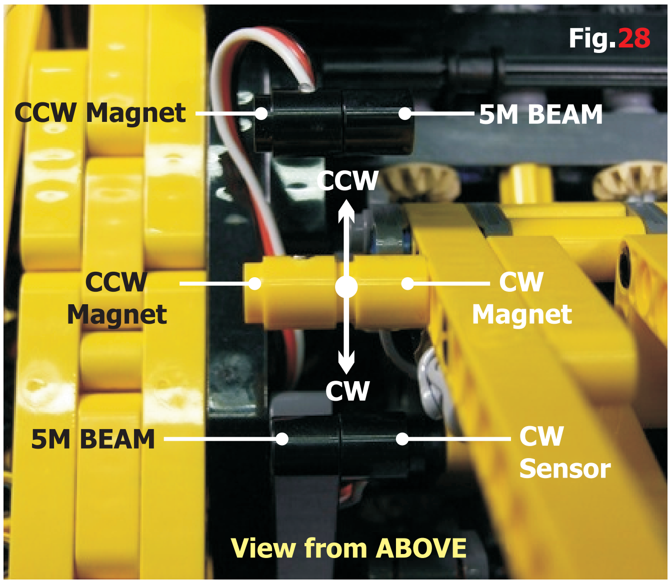


Fig.28



In **Figure 27** and **28** it is possible to see in detail the installation of two complete Sensors, both mounted on two 5-holes "BEAMS", hinged on the excavator frame.

For easy-of-installation and aesthetics, the two Magnets are fixed one above the other exploiting their "STUDs", rotated by 180 ° so as to be facing to the respective Sensors.

The Magnets, moving with the main excavator arm (BOOM), will be in proximity of the Sensors in the corresponding end-points of the BOOM stroke.

Fig.29

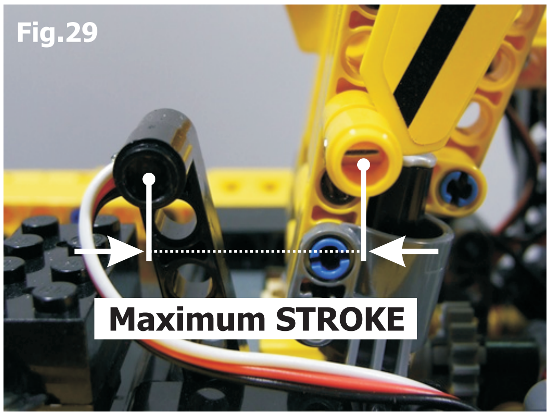
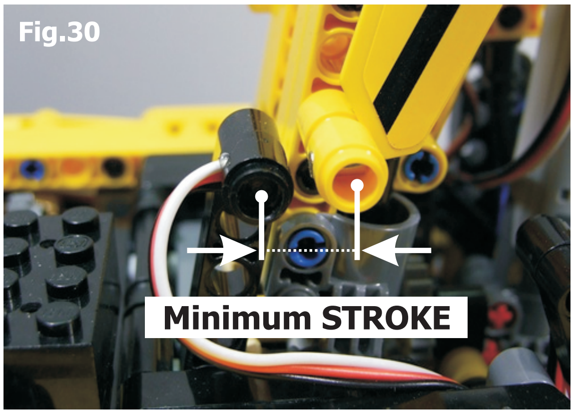


Fig.30



Moving the "BEAMs" on which are installed the Sensors, we can increase or decrease the stroke of the arm in both directions.

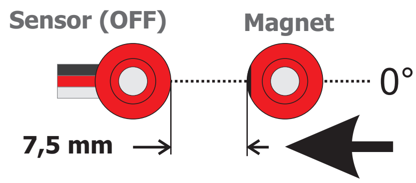
Moving the "BEAMs" away from the Magnet, the stroke will increase (**Figure 29**), while approaching will decrease (**Figure 30**); all intermediate positions between the two points, are obviously possible.

Hysteresis :

The last feature to describe in regard to the behavior of the Sensors is the one which is called as "Magnetic Hysteresis".

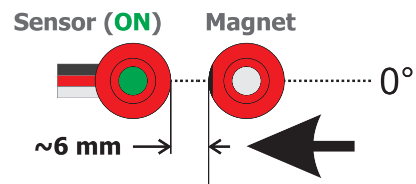
In practice, the Hysteresis is nothing else than a "delay" in the Sensor deactivation (from ON to OFF) at the time when the distance of the Magnet (in respect to the Sensor) increases than the minimum one necessary to activate a Sensor. A graphical example explains in better detail this situation:

Fig. A



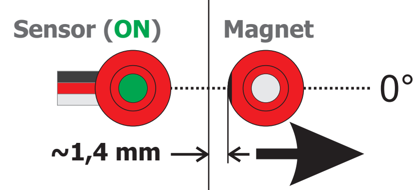
Supponing the Magnet (approaching the Sensor during its movement) is at a distance greater than the one of minimum activation (approximately 5/6 mm). In the example the Magnet is at 7.5 mm from the Sensor and, as a result, it is deactivated (OFF) - **Figure A**

Fig. B



When the distance between the two reaches 5/6 mm, the Sensor will bes activated and stops the movement, turning OFF the motor that it commands via the Blackbrick - **Figure B**

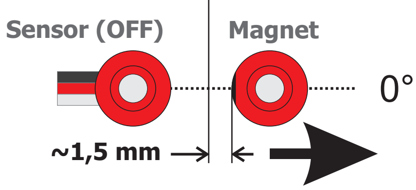
Fig. C



Once the movement is stopped, we reverse the direction of rotation of the motor via the Battery box or IR receiver, with consequent separation of the Magnet from the Sensor.

On the contrary to what we might expect, the Sensor will remain active for approximately another 1.5 mm of the Magnet stroke - **Figure C**

Fig. D



The Sensor deactivation will require a minimum further distance in the stroke of the Magnet - **Figure D**

The distance between the one of minimum activation (approximately 5/6 mm.) and the rate required to disable the Sensor (once activated) is approximately 1.5 to 1.6 mm.

This phenomenon is called HYSTERESIS and is proper of all devices with Magnetic characteristics.

In our application the Hysteresis ensures a perfect and repeatable activation of the Sensor, eliminating any uncertainty or instability phenomena.

The Hysteresis (ie the distance that the Magnet will have to travel, away, to turn off the Sensor after it has been activated) is also proportional to the Magnetic off-axis angle existing between Sensor and Magnet.

Wider this angle, and smaller the hysteresis ... the two factors are related in inverse proportion.

As described in the previous chapters of this Manual, "playing" with the opportunities offered by the Sensors and Magnets adjustment (sensitivity, rotation, distance and hysteresis), our "system" can be adjusted to perfection in order to obtain a perfect movement of the controlled Lego® Technic mechanism.