Measurement Excellence™

# BERTEC CORPORATION

# Force Plate User Manual

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CE

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## 2 Installation



## 3 Data Acquisition and Load Calculations

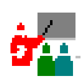
# 4 *Digital Data Acquisition Software*



# 5 *Technical Specifications*

# Typographical Conventions

For convenience, the following formatting conventions are used throughout this document.

| Formatting Convention | Type of information |
|---|---|
|   | Important messages. They state the **fundamental** things to keep in mind while using the *force plates*, including safety notices. The related text is printed in **bold**. |
|  | **Step-by-step procedures**. The procedure is identified by its title written in bold italic next to this symbol. |
|  | **Tip** messages. They state some useful information about the versatility of the force plates. The related text is printed in **bold.** |
| ***Bold Italic*** font type | **Reference to other sections** of the manual where the mentioned topic is described in detail. |

# 1 Introduction

## 1.1. Overview

Bertec's product line of force plates have been specifically designed for gait, balance, sports and other static and dynamic analyses. Through the use of strain gauge technology, innovative design, and quality manufacturing, Bertec's force plates are well suited for both static and dynamic applications. Each force plate consists of a number of strain gauged load transducer and a built-in digital pre-amplifier for signal conditioning. Bertec force plates come in a variety of sizes and associated load ranges to suit different application needs. The 4550, 4060 and 4080 series plates have been designed specifically for the demands of clinical and research gait analysis, whereas 6090, 9090 and 6012 series force plates are well suited for the rigors of sports and other dynamic biomechanics, ergonomics and industrial research. The rugged honeycomb technology used for the production of the tops and bases ensure enhanced dynamic measurement characteristics while keeping the overall weight to a minimum. All of the models can be portable in that they do not require separate mounting plates, and can be moved from one location to another. Smaller models, like 4550 and 4060, also have non-portable versions to be used with a mounting plate. Years of experience in force plate design enables Bertec to customize all models to suit customers' requirements. Most of the models, for example, can be retrofitted to be waterproof or the sizes of standard models can be modified for specific applications.

Bertec force plates are six-component load transducers, which measure the three orthogonal components of the resultant force acting on the plate, and the three components of the resultant moment in the same orthogonal coordinate system. The point of application of the force and the couple acting on the plate can be readily calculated from the measured force and moment components.

Bertec force plates use a state-of-the-art 16-bit digital technology for signal acquisition and conditioning. This new technology makes the use of calibration matrices obsolete, since each plate comes with the calibration matrix already digitally stored on it. External amplifiers to be used with force plates provide the user with three signal output alternatives: digital, analog or dual digital/analog outputs. The digital signal output can be directly plugged into the standard USB port of the personal computers without the requirement of an additional PC card for analog-to-digital (A/D) signal conversion. This plug-and-play technology allows a simpler installation procedure in a minimum amount of time. The digital data acquisition software, provided with the force plates as a standard item, enables the user to collect data quickly without the need of additional custom designed software. Upon request, software libraries and device drivers are available from Bertec so that the user can write his/her own digital data acquisition software.

The analog output of the force plates can be fed into an A/D board so that data can be collected using conventional techniques. Depending on application, signal amplification can be performed for analog output using external amplifiers. External amplifiers are either fixed gain (factory set according to customer requirements) or adjustable gain (seven adjustable gains). These amplifiers enable the user to establish a trade-off between the measurement range and resolution of the force plates.

The wide variety of force plates in Bertec's product line can be used with any type of motion analysis system ranging from camera-based systems using passive markers to systems with active markers or magnetic sensors. For example, the 4060-NC model is a non-conductive plate specifically designed to be used in environments requiring measurement of magnetic fields.

# 1.2. Customer Support

For any questions or inquiries regarding Bertec products you can contact:

**Bertec Corporation**
6171 Huntley Road, Suite J
Columbus, OH 43229, U.S.A.

Phone: +1 **614 430-5421**
Fax: +1 **614 430-5425**
e-mails: **sales@bertec.com, service@bertec.com**

**www.bertec.com**

Suggestions or comments about Bertec products are always welcomed.

# 2 Installation

## 2.1. Mounting the Force Plate

All Bertec force plates are pre-assembled in the factory. Therefore, they are ready to be installed by mounting them to the floor, and by connecting all the cables.


**Do not attempt to disassemble the force plate, damage can occur to the transducer components or electronics. The Limited Warranty is void if the force plate or any of the accessories are disassembled without the authorization of Bertec.**

To obtain a high quality measurement from Bertec force plates they should be installed in a way that is suitable for the type of measurement to be performed. First of all, the floor and structure underneath should be prepared to be as rigid as possible in order to minimize any vibrations. Bertec force plates are very sensitive devices. Therefore, they will pick up any vibration coming from the support structure. A second consideration is the flatness of the mounting surface. Bertec force plates are designed to work accurately on uneven surfaces. However, overstraining them during installation or while using, might introduce errors into the measurements.

Fixing the force plate to a surface is optional. If the application for the force plate involves high horizontal forces, which might cause the plate to slide, then it is strongly suggested that the plate be anchored using the mounting locations provided on the feet. Depending on the model used, an additional mounting plate might be necessary to fix the force plate to the floor.

For effective use the top surface of the force plate should be at the same level as the rest of the floor. For this purpose, a pit can be made in which the plate is mounted. Alternatively, a raised walkway can be used with the top surface of the walkway at the same height as the top of the force plate. No matter what methodology is used, remember to leave room for the output cable and make sure that the force plate does not touch any surrounding structure as this might result in measurement errors. A gap of 1-2 mm (0.04”-0.08”) between the force plate and surrounding floor will be appropriate. The following practical considerations will be helpful during installation. If you need additional assistance, please contact Bertec Corporation (see ***1.2. Customer Support***):

- **The pit should be deep enough to accommodate the height of both the force plate and mounting plate. Leave an additional ⅛”-¼” space for leveling tolerances.**
- **Size of the pit should be large enough to take future expansion plans into account, such as adding more force plates or other equipment.**
- **Allow at least 8” (20 cm) free space around the force plate so that the output cable is not crammed, and the wrench to tighten the mounting bolts can be operated easily.**
- **Incorporate a conduit into the construction plan so that the output cable will run under the floor. Make the conduit large enough for the cable connector to pass through. The minimum diameter for a straight conduit should be 1¾” (45 mm). If there are bends and corners in the conduit, then the recommended diameter is 3 inches (75 mm).**

## Without a Mounting Plate

Bertec force plates may be used on any type of surface. When used on a hard, non-flat surface shimming is required to prevent rocking of the plate (plain paper works fine for shimming small gaps up to 1/32”). When mounting to a concrete surface, Bertec recommends using threaded anchors permanently affixed to the concrete floor. The standard bolts to be used with force plates are of the size ⅜” – 16 UNC (or M8 – 1.25 for European customers). For the exact locations of the anchor points for different force plate models, please refer to section 5.2 Force Plates. Finally, the area where the plate is going to be mounted should be clean.

**Caution should be taken, however, when using unfixed force plates. Large shear forces may cause an unattached plate to move on the surface, which can be dangerous for both the subject and any by-standers. Bertec recommends avoiding the use of unfixed plates in these situations.**

**If you are not sure about the flatness of the mounting surface, then tighten the anchoring bolts as little as possible to avoid bending the base of the force plate. Make sure that the only contact is between the feet and mounting surface, and the entire surface below the feet is properly shimmed.**

## Using a Mounting Plate

Standard Mounting Plates are ¾” (19 mm) thick and have the same dimensions as the force plate. The Mounting Plates come with pre-tapped holes that mach the anchor locations on the feet of the force plate, along with leveling hardware. Typically, the Mounting Plate is rigidly affixed to the floor with a high strength epoxy. Then, the plate is mounted onto the mounting plate via four hexagonal cap screws of size ⅜" – 16 UNC (or M8 – 1.25). The following installation hardware is provided with the Mounting Plate:

- High Strength Epoxy – to glue the Mounting Plate
- Trowel and Putty Knife – to spread the epoxy on the floor
- Water Level – to adjust the levelness of the force plate
- Hexagonal Allen Key – to adjust the set screws on the Mounting Plate
- Eye Bolts – to lift the Mounting Plate
- Hexagonal Cap Screws – to attach force plate to the Mounting Plate

Please read all instructions before installing the Mounting Plate:

***Mounting Plate Installation***

- Place mounting plate on concrete floor in desired location. Ensure that the setscrews on the Mounting Plate are not touching the floor at this point (depending on the size of the Mounting Plate there may be four (4) or more set screws). The provided eyebolts may be used in the force plate mounting locations to make lifting of the Mounting Plate easier.

**Figure 2.1 –** The eyebolts can be used to lift the plate. The adjustable setscrews are used to level the Mounting Plate

- Assemble the force plate to Mounting Plate using outer corner holes with provided bolts (⅜"–16 UNC or M8–1.25) and washers.
- Level force plate using the outer accessible setscrews (the ones closer to the edge of Mounting Plate). The water scale provided can be used on top of the force plate if necessary. Make sure that Mounting Plate is lifted from the floor at least 1/16–1/8 inches (2–3 mm) to allow room for the glue. If the force plate

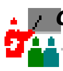
is to be mounted in a pit, which does not provide easy access to the setscrews, the Mounting Plate can be leveled first. However, make sure that the top of the force plate is flush with the surrounding floor before proceeding further.

**Figure 2.2 –** The Mounting Plate can be leveled while the force plate is mounted on it.

- Mark outer perimeter of the Mounting Plate on the floor.
- Disassemble force plate from Mounting Plate, leaving Mounting Plate in position.
- Adjust any unadjusted setscrews in the middle of the Mounting Plate just to touch floor. When working with large Mounting Plates make sure that the plate has not sagged in the middle. If necessary further adjust with central set screws.
- Remove the Mounting Plate. Make sure that the setscrew adjustments do not change.
- Mix the two parts of the epoxy adhesive (1:1 ratio) in the plastic bucket provided. Make sure that the epoxy and the hardener is thoroughly mixed (about 5 minutes by hand). The working life of the epoxy is 30 minutes.
- Spread the epoxy on the floor, within the marked area, using the notched trowel provided. The notches of the trowel will help form “hills and valleys” of epoxy so that when Mounting Plate is placed back on it, the epoxy has room to spread.
- Relocate the Mounting Plate back to the marked area.
- Allow epoxy adhesive to cure overnight before assembling force plate.
- Mount the force plate to the Mounting Plate using the supplied screws (⅜” – 16 UNC or M8 – 1.25) and washers.

# 2.2. Cables and Amplifier Connections

After the force plate is mounted onto the floor, the next step in the installation is making the cable connections with external amplifiers and the computer. The standard output of Bertec force plates is an 8-pin male round receptacle. The standard output cable is 10 m (33') long, has an 8-pin round female connector at the force plate end, and a 9-pin male D-Sub connector at the other end. The first step is to connect the force plate output cable to the force plate:



***Connecting Force Plate Cable***

- Identify the 8-pin female round connector on the force plate output cable.
- Match the keys of the plug and receptacle.
- Push in the connector and rotate (about ¼ turn) clockwise until the two fully engage and lock.

Depending on the configuration of the system, the 9-pin male connector plugs into an external amplifier or signal converter. Analog output from Bertec signal conditioning amplifiers is a standard 15-pin female D-Sub connector. The output of the external amplifier connects to the computer used for data acquisition. For analog outputs an additional A/D signal conversion card on the PC is necessary. Digital output of the amplifiers plugs directly into the USB port of the computer using the USB cable provided with the system. Pin configuration for the analog output is given in ***Chapter 5: Technical Specifications***.

Additional analog output cables to connect amplifiers to A/D boards are available from Bertec Corporation. One end of these cables is always a 15-pin male D-Sub connector, which plugs into the amplifier. The other end is manufactured depending on specific customer order (e.g. BNC, bare wire leads, etc.).

**Whatever system configuration you use, the electrical network, that is used to supply power to the data acquisition systems and force plates, should be properly grounded. Poor grounding is a common source of signal noise in electronic systems. Although, all Bertec force plates and amplifiers carry the CE mark of the European Union to ensure high signal quality, improper grounding and external power sources might degrade signal characteristics.**


**Force plate cables can be a hazard for tripping. It is recommended that these cables be routed to prevent tripping. Alternatively, use masking tape, or some other non-permanent means to hold the cables to the floor.**

# 3 Data Acquisition and Load Calculations

## 3.1. Overview

All Bertec products use a novel 16-bit digital technology for signal acquisition and conditioning. The output signal of the load transducers are already digitized and conditioned in the force plate by using state-of-the-art electronics developed by Bertec Corporation. With this new technology the output signal has a very high signal-to-noise ratio, which means increased sensitivity and accuracy for the force plates. In addition, the digital technology makes the use of calibration matrices obsolete, since each plate comes with the calibration matrix already digitally stored on it. Depending on the configuration, the system provides the user with a digital, analog or dual digital/analog output.

The digital output of the system is always in the form of calibrated data in their respective units selected by the user (N and N·m, or lb and lb·in). The analog output requires an additional scaling depending on the external amplification used in data acquisition.

## 3.2. Analog Data Acquisition

The output of the force plate is in the form of a 16-bit digital signal. External digital-to-analog (D/A) converters are used in order to obtain analog output to be used in conventional data acquisition systems. The D/A converters are also analog amplifiers with either a fixed (65XX series) or adjustable gain (6800 series) setting (for a detailed description of amplifiers please refer to ***5.3 Amplifiers***). The pin configuration for the 15-pin analog output is given in Chapter ***5. Technical Specifications***.

**Before starting to collect data, make sure that the cables from the force plate to the amplifier, and from the amplifier to the PC is properly connected. Power to the amplifier should be connected, and the amplifier should be turned on (in 6800 series only).**

**The force transducer system reaches thermal stability in about 5 minutes. Therefore, always allow the equipment to warm up at least for 5 minutes before collecting data.**

## Auto Zero

All analog amplifiers are equipped with an "*Auto Zero*" button. This button allows zeroing offset loads up to full scale. This functionality can be used to remove tare weight of equipment such as a chair or a step, placed onto the force plate as part of the measurement protocol. When the amplifier is first turned on, of the two green lights next to the *auto zero* button, only the bottom one will be on, confirming that the amplifier is powered. This indicates that zero has not been set yet. Simply press and release the *auto zero* button in order to zero the bridges on the amplifier. When zero is set, both lights next to the *auto zero* switch will be on.

For the variable gain 6800 series amplifiers, the *auto zero* switch is next to the power switch on the front panel. For the fixed gain amplifiers (65XX series) it is located next to the 15-pin output connector.

**Note that auto zeroing sets all channels to near zero. True zeroing should be done by software at the time of data collection, by subtracting a baseline reading from the collected data.**

The analog data acquisition procedure can be summarized as follows:

***Analog Data Acquisition***

- Check all the cables, and make sure that they are properly connected.
- Turn on the amplifiers, and allow the system to warm up at least for 5 minutes.
- For the 6800 series variable gain amplifiers, set a proper gain value for the data channels using the gain switch on the front panel of the amplifier.
- Press the *auto zero* button in order to remove any offset load on the force plate.
- Collect analog data using software. Remember to remove a baseline reading from the signals using software in order to set the signal mean values to true zero.

# Calculating Load Values

Each force plate is calibrated individually and the calibration matrix is stored digitally in the force plate. Therefore, the analog output from the amplifier provides full-scale calibrated output (±5 V) per rated load range of the attached force plate. The voltage output of each channel is a scaled form of the load in the units of N and N·m for the forces and moments respectively. The scale factor for each channel for a gain of unity is given in the product data sheet supplied with the transducer. The force and moment values are calculated by multiplying the signal values with corresponding scale factors, as given in Eqn. 1:

$$\begin{aligned} F_x &= C_1 \cdot S_1 \\ F_y &= C_2 \cdot S_2 \\ F_z &= C_3 \cdot S_3 \\ M_x &= C_4 \cdot S_4 \\ M_y &= C_5 \cdot S_5 \\ M_z &= C_6 \cdot S_6 \end{aligned} \qquad (1)$$

where, F's and M's are the force and moment components in the force transducer coordinate system (Figure 3.1), and S's are the output signals corresponding to the channels indicated by their subscripts, in volts, divided by the respective channel gain. The origin of the coordinate system is centered on the top surface of the force plate (see Figure 3.1). The standard coordinate system is such that the positive y-direction is opposite to the connector end; x-axis is to the left when looking in the y-axis direction; and the z-axis is defined downwards by the right hand rule.

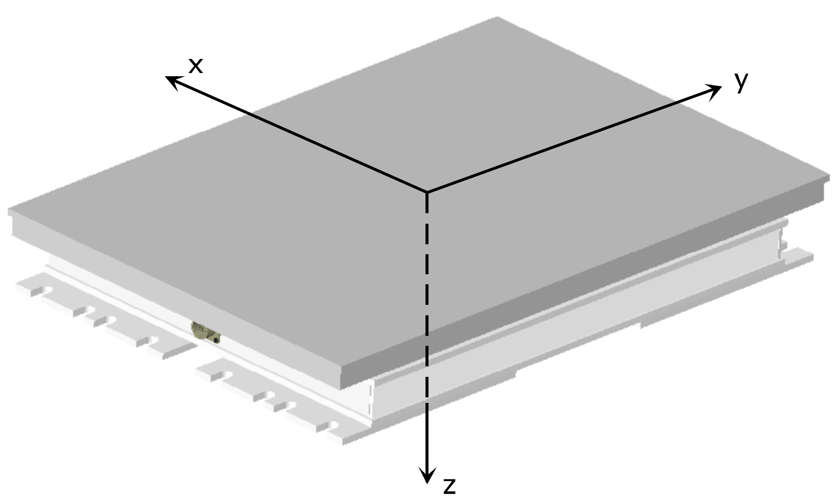



**Figure 3.1–** Standard force plate coordinate system: the origin is on the top surface, and at the center of the plate. Positive y-direction is opposite to the connector end; x-axis is to the left when looking in the y-axis; and the z-axis is defined downwards by the right hand rule.

# Calculation of Point of Application for the Force and Couple

A load system acting on a force plate can be completely described by the six load components (i.e. the three force and three moment components) calculated from Eqn. 1. Alternatively, the same information can be given as the three force components, the point of application of the force vector ($x_p$, $y_p$ in Figure 3.2), and a couple (sometimes also referred as "torque " or "free moment") acting on the force plate. Referring to Figure 3.2, the point of application of the force, and the couple are calculated from the force and moment components as:

$$x_p = \frac{-h \cdot F_x - M_y}{F_z}$$
$$y_p = \frac{-h \cdot F_y + M_x}{F_z} \qquad (2)$$
$$T_z = M_z - x_p \cdot F_y + y_p \cdot F_x$$

where, $x_p$ and $y_p$ are the coordinates of the point of application for the force (i.e. center of pressure); $h$ is the thickness, above the top surface, of any material covering the force plate (Figure 3.2); and $T_z$ is the couple acting on the force plate. Note that the thickness $h$, shown in Figure 3.2, is to be entered as a positive number in Eqn. 2.

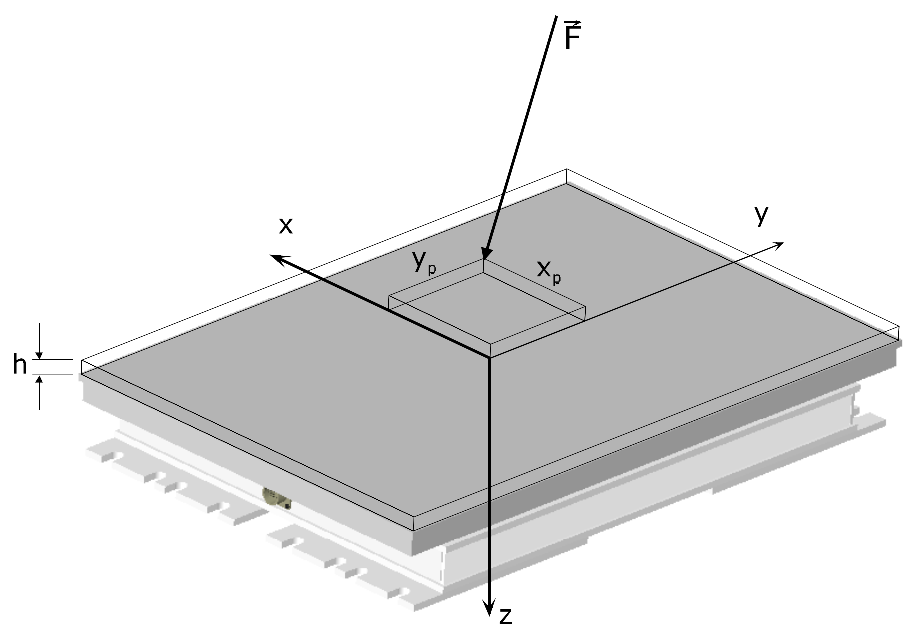



**Figure 3.2 –** A force F, and the point of application of the force. The force plate is covered with a layer of floor covering, which has a thickness ***h***. The thickness ***h*** is entered as positive number in Eqn. 2.

# Example 1: Load Computation

Consider a case where the external amplifier gain is set to 10 (note that the gain value is always the same for all of the six channels). If, at an instant in time, the amplifier voltage outputs for the six channels are:

| CHANNEL | OUTPUT, V |
|---|---|
| 1 | -1.450 |
| 2 | 2.235 |
| 3 | 4.765 |
| 4 | 3.095 |
| 5 | -0.575 |
| 6 | -1.016 |

Then, by dividing each output by the corresponding gain, the output signal values to be used in Eqn. 1 are obtained:

$S_1 = -1.450/10 = -0.145$ V

$S_2 = 2.235/10 = 0.2235$ V

$S_3 = 4.765/10 = 0.4765$ V

$S_4 = 3.095/10 = 0.3095$ V

$S_5 = -0.575/10 = -0.0575$ V

$S_6 = -1.016/10 = -0.1016$ V

Let us use hypothetical scale factors, in N/V and N·m/V[1]:

$C_1 = 1000$ N/V

$C_2 = 1000$ N/V

$C_3 = 1500$ N/V

$C_4 = 300$ N·m/V

$C_5 = 300$ N·m/V

$C_6 = 250$ N·m/V

Then from Eqn. 1:

[1] Note that if the results are needed in English Units, an alternative to converting them at the end of calculations is to convert the scale factors to English Units by converting the first three factors from N/V to lb/V, and the last three factors from N·m/V to ft·lb/V. This can be done by multiplying the first three scale factors by 0.2248 lb/N, and last three scale factors by 0.7377 (ft·lb)/(N·m).

$F_x = 1000 \cdot (-0.145) = -145.0$ N

$F_y = 1000 \cdot (0.2235) = 223.5$ N

$F_z = 1500 \cdot (0.4765) = 714.8$ N

$M_x = 300 \cdot (0.3095) = 92.9$ N·m

$M_y = 300 \cdot (-0.0575) = -17.3$ N·m

$M_z = 250 \cdot (-0.1016) = 25.4$ N·m

To calculate the point of application of the force, Eqn. 2 is used. Assuming there is a 5 mm covering on the top surface of the transducer, then *h*=0.005 m. Therefore:

$$x_p = \frac{(-0.005)\cdot(-145.0) + 17.3}{714.8} = 0.025\,\text{m}$$

$$y_p = \frac{(-0.005)\cdot(223.5) + 92.9}{714.8} = 0.128\,\text{m}$$

## Change of Coordinate System

In numerous applications measurement protocols require that the forces and moments be measured with respect to a coordinate system other than the force plate's local coordinate system shown in Figure 3.1. This secondary coordinate system might be that of a motion analysis system or it might belong to another force plate. In such a case the components of force and moment vectors should be expressed in this secondary system. For this purpose, the exact location and orientation of the secondary coordinate system with respect to the force plate local system should be known. For the case shown in Figure 3.3, coordinate system 1 is the force plate's local coordinate system, and a secondary system 2 is located so that its axes are rotated and displaced in 3-dimensional space. The rotational displacement is such that the angle between axes are given in terms of angles $\theta_{11}$, $\theta_{12}$, … $\theta_{33}$, where $\theta_{ij}$ (i=1, 2, 3; j=1, 2, 3) is the angle between the unit vectors $\vec{u}_i^1$ and $\vec{u}_j^2$ of the two coordinate systems shown in Figure 3.3. The displacement of the origin of 1 with respect to 2 is given as the vector $\vec{r} = \{r_1 \quad r_2 \quad r_3\}$, where $r_1$, $r_2$ and $r_3$ are measured in the second coordinate system. The measured forces and moments can be transformed to coordinate system 2 using the following relations:

$$\begin{Bmatrix} F_x^2 \\ F_y^2 \\ F_z^2 \end{Bmatrix} = [T] \cdot \begin{Bmatrix} F_x^1 \\ F_y^1 \\ F_z^1 \end{Bmatrix} \qquad (3)$$

$$\begin{Bmatrix} M_x^2 \\ M_y^2 \\ M_z^2 \end{Bmatrix} = [T] \cdot \begin{Bmatrix} M_x^1 \\ M_y^1 \\ M_z^1 \end{Bmatrix} + \vec{r} \times \begin{Bmatrix} F_x^2 \\ F_y^2 \\ F_z^2 \end{Bmatrix} \quad (4)$$

where, superscript "1" denotes measured quantities, superscript "2" indicates the same quantities expressed in coordinate system 2, and [*T*] is a transformation matrix computed using the $\theta_{ij}$ values described above. The elements of the 3x3 transformation matrix are the direction cosines of the coordinate axes arranged as:

$$[T] = \begin{bmatrix} \cos\theta_{11} & \cos\theta_{12} & \cos\theta_{13} \\ \cos\theta_{21} & \cos\theta_{22} & \cos\theta_{23} \\ \cos\theta_{31} & \cos\theta_{32} & \cos\theta_{33} \end{bmatrix}$$

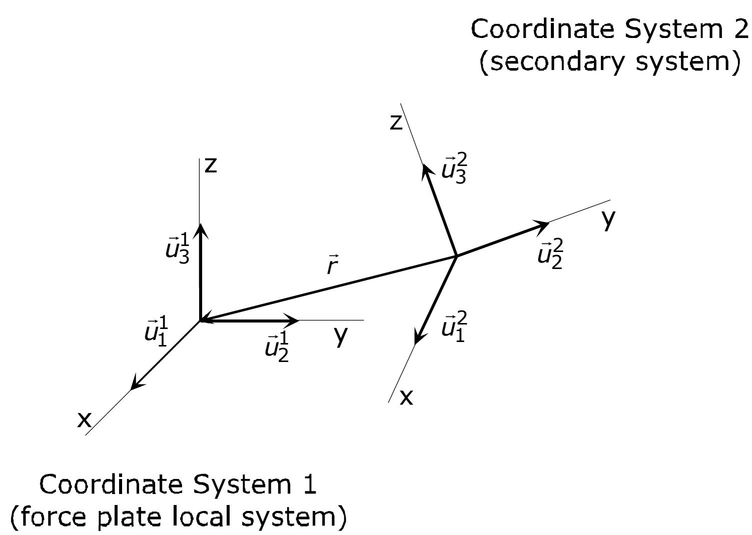



**Figure 3.3 –** Coordinate system 1 is a force plate's local coordinate system in which the loads are measured. The secondary coordinate system is displaced and rotated with respect to the first in 3-dimensional space.

# Example 2: Change of Reference System

Let's assume that in a gait analysis laboratory the ground reaction forces and moments are measured in the force plate local coordinate system with the axes $x_f$, $y_f$, $z_f$ shown in Figure 3.4. The motion analysis system, however, requires these loads to be computed in a laboratory fixed coordinate system located at the corner of the force plate with the axes $x_L$, $y_L$, $z_L$. oriented as given in Figure 3.4. The x and z-axes of both coordinate systems are pointing in opposite directions rotated by 180º, and the y-axes are parallel to each other. The origins are displaced by 20 cm in x-direction, and 30 cm in y-direction. For such an arrangement the vector $\vec{r}$ will be {0.2 0.3 0} m. Since the corresponding coordinate axes are parallel to each other we have the following values for the angles θ:

$$\theta_{11} = 180º, \theta_{22} = 0º, \theta_{33} = 180º$$

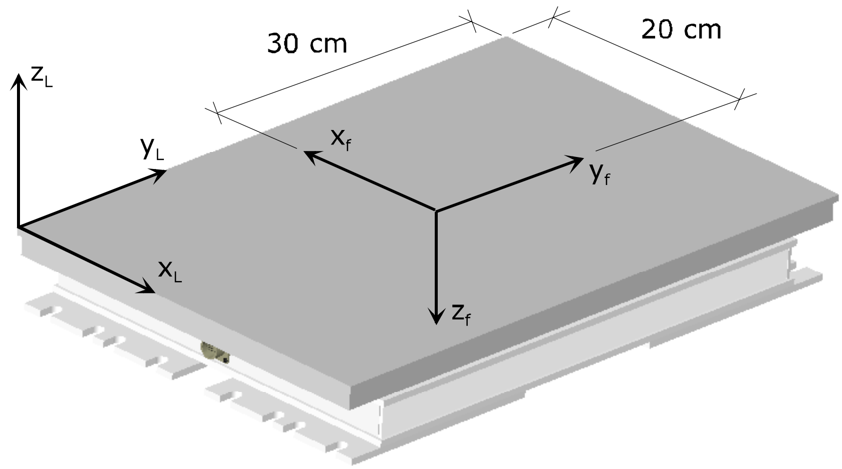



**Figure 3.4 –** The ground reaction load is measured in the force plate's local coordinate system denoted by the subscript "f". Then the components of the force and moment vectors are transferred to the laboratory coordinate system indicated by the subscript "L".

The rest of the angles are either 90º or -90º. Using these values the transformation matrix is calculated as:

$$[T] = \begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{bmatrix}$$

Using the hypothetical measured values calculated in Example 1 above in Equations 3 and 4, we get

$$\begin{Bmatrix} F_x^2 \\ F_y^2 \\ F_z^2 \end{Bmatrix} = \begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \cdot \begin{Bmatrix} -145.0 \\ 223.5 \\ 714.8 \end{Bmatrix} = \begin{Bmatrix} 145.0 \\ 223.5 \\ -714.8 \end{Bmatrix} \text{N}$$

$$\begin{Bmatrix} M_x^2 \\ M_y^2 \\ M_z^2 \end{Bmatrix} = \begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \cdot \begin{Bmatrix} 92.9 \\ -17.3 \\ 25.4 \end{Bmatrix} + \begin{Bmatrix} 0.2 \\ 0.3 \\ 0 \end{Bmatrix} \times \begin{Bmatrix} 145.0 \\ 223.5 \\ -714.8 \end{Bmatrix}$$

$$\begin{Bmatrix} M_x^2 \\ M_y^2 \\ M_z^2 \end{Bmatrix} = \begin{Bmatrix} -307.3 \\ 125.7 \\ -24.2 \end{Bmatrix} \mathrm{N \cdot m}$$

# 3.3. Digital Data Acquisition

The output of Bertec force plates is a 16-bit digital signal, which is converted to USB via an external converter (AM6500 or AM6800). The USB output plugs into the USB port of the computer and requires no additional A/D conversion.

The digital data acquisition software, ACQ, provided with the force plate can be used to collect data using the digital output. The software can be utilized to collect data from the six channels of the force plate, and save it in a text file as column formatted text so that it can easily be imported using spread sheet programs such as Microsoft® Excel for further analysis. The detailed procedure on how to install and use the software is given in Chapter ***4. Digital Data Acquisition Software***. For the analysis of the collected data, please refer ***to 3.2 Calculation of Point of Application for the Force and Couple***.

**The AM6500 series external digital converter can be powered from the USB port of the computer. Therefore, in order to warm up, the force plate cable should be connected, and the amplifier should be plugged into the computer for at least 5 minutes prior to data collection, and the computer should be turned on.**

**The *auto zero* button on the AM6800 series amplifiers is not functional for digital data acquisition. The ACQ software has a software zero capability (both manual and automated) to remove signal offset.**

***Digital Data Acquisition***

- Check all the cables, and make sure that they are properly connected.
- Turn on the external amplifiers, and allow the system to warm up at least for 5 minutes.
- Collect force plate data using software. Remember to remove a baseline reading from the signals using software in order to set the baseline to true zero (see Chapter ***4. Digital Data Acquisition Software***).

# 4 Digital Data Acquisition Software

## 4.1. Overview

The data acquisition software Digital Acquire (ACQ) is designed to collect data from a single force plate, and save it to a text file. The text file is formatted in columns so that spread sheet programs such as Microsoft® Excel can easily be used to read and analyze data.

ACQ uses the digital USB output of the force plate to interface it. Data is read from the force plate already in calibrated form. Therefore, no calibration matrix or analog scale factors are needed to use the software program. ACQ incorporates many features such as manual and automated software zero capability, real-time display of center of pressure (CoP) and vertical force value, fixed or variable time data acquisition periods. Digital filters with preset cutoff frequency values can be applied to the collected data before saving it to a file. Data channels to be saved can be selected individually so that excessive data does not take up valuable disk space on the computer.

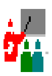
Once the force plate is connected to the USB port of the computer, the software automatically recognizes the particular plate connected, and displays the serial number. If a cable gets disconnected, a warning message is displayed immediately.


**The ACQ software is written to collect data using the digital output of the force plate from AM6500 or AM6800 amplifiers via the USB port of the computer. It will not work with the analog output of the AM65XX or AM6800 amplifiers.**

# 4.2. Software Installation

The installation program for the ACQ software is provided on a CD-ROM labeled "*Digital Acquire*". The program is a self-installing program, and it starts automatically once the disk is inserted into the CD-ROM drive of the computer. Before proceeding with the installation make sure that the force plate cable is connected to the force plate (8-pin round connector), and to the external amplifier/converter (AM6500 or AM6800, 9-pin D-Sub connector). Connect the USB cable to the amplifier/converter only.


**Do not plug the USB cable into the computer yet. For a proper installation, the USB cable should be plugged to the USB port of the computer after the software is installed.**



***Software Installation***

- Turn on your computer.
- Insert the CD-ROM labeled ***Digital Acquire***™ into the CD-ROM drive of your computer.
- The installation software starts automatically, and the following window is displayed:

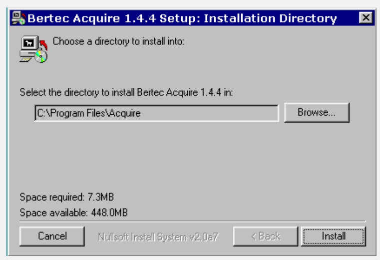
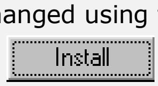



**Figure 4.1.** *Software Installation Window 1*

- The ***Digital Acquire***™ software is installed by default under the directory "C:\Program Files\BalanceCheck". The installation directory can be changed using the "Browse" button.
- Click the  button.

- The following window will display steps of the installation procedure:

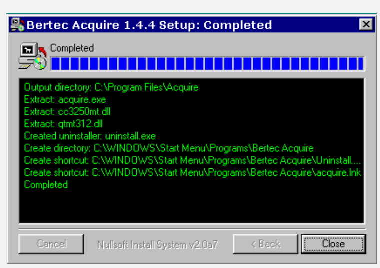



**Figure 4.2** *Software Installation Window 2*

- After you see the "Completed" message in the window click the Close button to finish software installation.
- **Do not remove the CD-ROM yet.**
- Plug the USB cable into the USB port of the computer. After a few seconds the following window will appear:


**Figure 4.3**. *Driver Installation Window 1*

- Click Next > button **<u>twice</u>** To display the following window:


**Figure 4.4.** ***Driver Installation Window 2***

- Check the box next to the "CD-ROM Drive" option, and click Next > button.
- The computer will prompt with the following window to show that the USB driver of the platform is found on the CD-ROM:

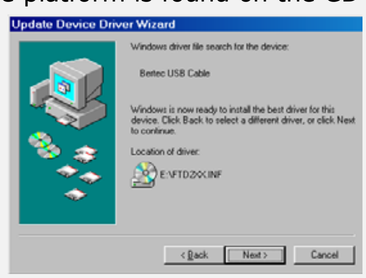



**Figure 4.5.** ***Driver Installation Window 3***

- Click the Next > button.
- After the USB driver is successfully installed, the following window will show up:

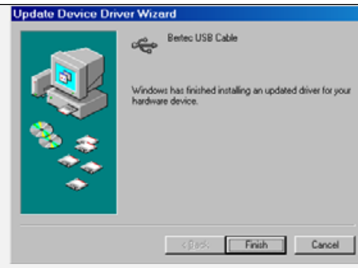



**Figure 4.6*. Driver Installation Window 4***

- Click the [Finish] button to finish the installation procedure.
- If you have any problems during the installation procedure please contact customer service.

# 4.3. Using the Software

Once the software is properly installed it can be started by clicking "**Start**" on the Windows® desktop and then selecting "**Programs**" and "**Bertec Acquire**" from the list. Then click on the "**Acquire**" entity and the program will start. Before starting the program, make sure that all the cables to the force plate, external amplifier (AM6500 or AM6800), and computer are properly connected. The data acquisition program consists of a single window incorporating all the controls and features for collecting data from Bertec force plates. Figure 4.7 shows the main window of the software.

The main window is divided into three sections: *Acquisition*, *Acquired Channels* and *Status*. The Acquisition field is used to set parameters related to data collection such as name of the file to save data, length of data acquisition period, digital filter cutoff frequency, and selection of manual or automatic software zero feature. The Acquired Channels field allows selection of the data channels to be saved. The Status section displays information related to the current status of the system including data sampling frequency, serial number of the force plate connected to the computer, current value of the load in $F_z$ direction, and the location of center of pressure (CoP) in real time. This section also includes a progress bar displaying the percentage of data collection completed during timed acquisition. Next to the progress bar is a message displaying whether the force plate is loaded or unloaded.

## File Name

In order to save the data to a file, the *File Name* field should designate a valid file name and location. The location and name can either be entered manually or the *Choose* button next to the field can be clicked to select a specific file and location. Data will be saved as a column formatted text file where each column contains data from a different channel. If the file name belongs to an existing file, the program will prompt with a confirmation message to overwrite the file before starting data acquisition.

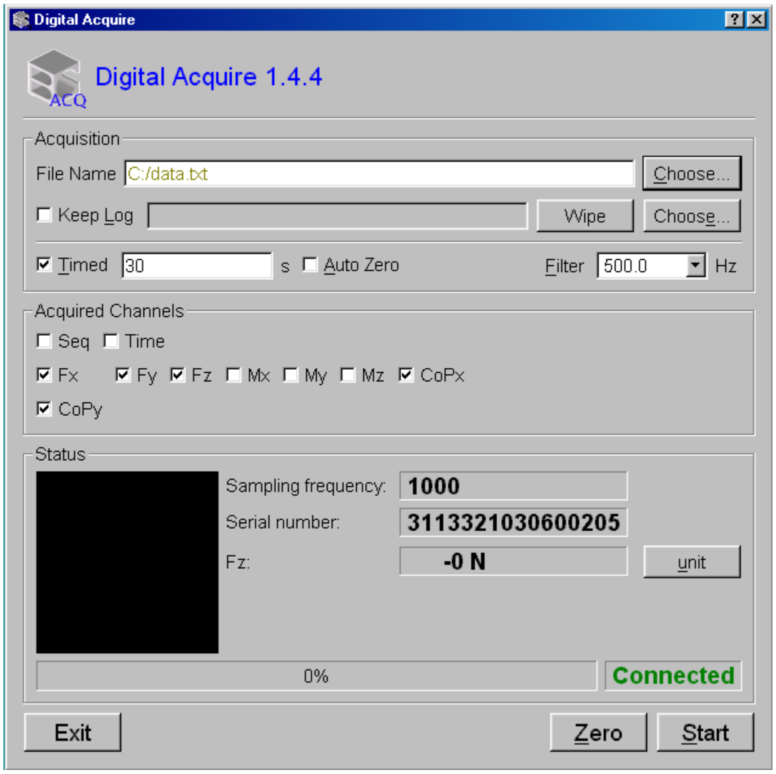



**Figure 4.7 –** The ACQ software consists of a single window incorporating all of its functionality.

# Data Acquisition Interval

The length for the data acquisition interval can either be fixed or variable. A fixed time period for data acquisition can be set by checking the *Timed* box, and entering a period length in seconds. Data collection can be started by pressing the *Start* button, and it will stop automatically after the specified time period runs out. If the *Timed* button is not checked, then data collection period has no time limit, and the user should stop data collection manually. For user controlled time period, data collection starts by pressing the *Start* button. As soon as this button is pressed, it will transform into a *Stop* button, which can then be used to terminate data collection. The variable time data collection feature relieves the user from the guesswork of how long the data collection period should be set in order not to miss valuable data.

# Software Zero

The ACQ software incorporates the capability of removing the signal offset due to additional equipment on the force plate. The *Software Zero* feature sets the mean values of the signals from all channels to zero. *Software Zero* can be performed both manually and automatically. Pressing the *Zero* button at the bottom of the window will remove the offset in each signal channel. Alternatively, checking the *Auto Zero* box will result the software to take a zero automatically every 3 seconds when it is not loaded. In this case two square marks appears next to the $F_z$ load display to indicate that automatic software zero function is turned on. This feature is active only when the load in the $F_z$ channel is below a certain value (about 8 lb), and the variations in the signal are negligible.

**In order to use the automatic zero feature with heavy objects, put the object on the force plate, zero the signals manually using *Zero* button while the automatic zero function is turned on by checking the *Auto Zero* box.**

## Applying a Digital Filter

The sampling frequency for data acquisition is fixed at a value of 1000 Hz. The force plate itself has an analog anti-aliasing filter of 500 Hz. Additionally, a digital software filter can be applied by selecting from a list of preset cutoff frequencies listed in the drop-down menu of the filter box. The drop-down menu lists nine different cutoff frequencies: 500, 333, 250, 200, 167, 143, 125, 111 and 100 Hz. The highest frequency, 500 Hz, belongs to the anti-aliasing filter, no additional filtering is applied in the software. The other cutoff frequencies are achieved by averaging successive data points. In other words, averaging 3 sequential data points yields 333 Hz, 4 data points provides 250 Hz, etc.

## Selecting Data to Be Saved

Individual channel data to be saved can be chosen selectively by using the check boxes in the *Acquired Channels* field. Ten check boxes are available in this field, six of them belonging to the force and moment channels of the force plate, two to the coordinates of the center of pressure (CoP). The forces are saved in Newtons (N), the moments in Newton-meters (N·m), and the coordinates of CoP in meters (m). If the "*Seq*" box is checked the first column of the data file contains a sequential number starting at 1 and incremented by 1. The last number in this column gives the total number of data points saved for each channel. If the *Time* box is checked then the data file includes a column with absolute time values corresponding to each sample collected. The values of this column are incremented by the amount equal to $1/f_s$, where $f_s$ is the sampling frequency of the data.

## The Status Field

The status field displays three numerical values; the fixed sampling frequency, the serial number of the force plate connected to the computer and a real-time value of the force in $F_z$ channel of the force plate. The *unit* button can be used to change the unit of the displayed force. Pressing this button swaps the unit between Newtons (N), pounds (lb) and kilograms (kg) sequentially. In addition, a real-time display shows the location of the Center of Pressure as a "**+**" cursor.

# Data Collection

A step-by-step procedure for data collection is as follows:

***Data Collection***

- Check all the cables, and make sure that they are properly connected.
- Turn on the external amplifiers, and allow the system to warm up for at least 5 minutes.
- Start the ACQ software by double clicking on the icon on the desktop of the Windows® operating system.
- Make sure that the serial number of the force plate is displayed correctly. If not, check the cable connections.
- Enter or choose the name and location of the text file for the data to be saved.
- If you want a fixed time interval for data collection, check the *Timed* box, and enter an interval length in seconds. If you want to start and stop data collection manually, uncheck the *Timed* box.
- If you want the software to remove signal offset periodically by taking a software zero, check the *Auto Zero* box. If you do not check this box, zero the signals by pressing the *Zero* button before each data collection.
- If you want to filter the collected data digitally, select a cutoff frequency from the *Filter* drop-down menu. Leaving the filter cutoff at 500 Hz will result in no filtering.
- Select the channels you want to save in the *Acquired Channels* field.
- If the *Auto Zero* box is not checked, then press the *Zero* button for manual signal offset removal.
- Press the *Start* button to start data collection.
- If the *Timed* box is not checked, press the *Stop* button to stop data collection process. If this box is checked, then data acquisition will stop automatically after the specified time interval expires.
- Data will be saved to the file that you specified while collecting data. Therefore, no additional action is required.

# 5 Technical Specifications

## 5.1. Overview

Bertec force plates are designed to cover a wide range of technical specifications to meet the needs of clinicians and researchers from a variety of fields. Standard force plates are available in different sizes and load capacities, which can further be customized depending upon the requirements of the measurements to be performed. The popular 4550, 4060 and 4080 series are the gold standard for gait analysis studies, while larger sizes such as the 6090, 9090 and 6012 series are well suited for the rigors of sports, ergonomics, industrial, and other dynamic biomechanical applications.

The measured signals from strain gauge based force transducers are amplified, filtered and digitized in the force plate, which minimizes signal degradation due to external noise sources during analog signal transportation. The output of the force plate is a 16-bit single channel, serial, digital signal, which can be transported over very long distances without any loss of quality. The digital output can be directly connected to the USB port of the computer or it can be fed into an external amplifier and converted into six individual analog signals to be connected to an A/D card. All the electronics of the force plates are designed and developed by Bertec Corporation. Analog and digital external amplifiers are designed so that measurement load range and sensitivity can be selectively optimized.

Deciding on a particular model is not a trivial task, and requires a careful evaluation of the needs and technical specifications of the force plates. Type of studies to be performed, available space, other equipment to be used with the force plate and available budget are among the many important deciding factors in selecting force plates. Furthermore, depending on the application a suitable force plate – amplifier combination should be selected.

This chapter provides the basic information about the mechanical and electrical properties of the force plates and amplifiers. If you have additional questions, please contact Bertec Corporation (see ***1.2 Customer Support***).

# 5.2. Force Plates

Basic technical specifications for the particular force plate that you have are given on the data sheet at the back of this user guide. Table 5.1 below gives the specifications for standard configuration force plates[2].


**The technical specifications for the particular force plate you have, might be different then those given in Table 5.1. Please check product specific data sheet at the end of this user manual.**

**Table 5-1** Technical Information for Various Force Plate Models

| MODEL | SIZE (mm) | | | WEIGHT (kg) | RATED LOAD (kN) | | NATURAL FREQUENCY* (Hz) | | |
|---|---|---|---|---|---|---|---|---|---|
| | L | W | H | | $F_z$ | $F_x$, $F_y$ | $F_z$ | $F_x$ | $F_y$ |
| 4060-08 | | | 83 | 28 | 10 | 5 | 340 | 550 | 540 |
| 4060-10 | 600 | 400 | 100 | 22.6 | 20 | 10 | 600 | 580 | 580 |
| 4060-15 | | | 150 | 23.5 | 20 | 10 | 750 | 570 | 550 |
| 4550-08 | 508 | 464 | 83 | 26.3 | 10 | 5 | 380 | 550 | 540 |
| 4060-NC | 600 | 400 | 100 | 25.9 | 10 | 5 | 480 | 500 | 500 |
| 4080-10 | 800 | 400 | 100 | 25.2 | 10 | 5 | 430 | 460 | 460 |
| 4080-15 | | | 150 | 26.2 | 20 | 10 | 540 | 460 | 460 |
| 6090-15 | 900 | 600 | 150 | 28.8 | 20 | 10 | 400 | 450 | 450 |
| 9090-15 | 900 | 900 | 150 | 31.8 | 20 | 10 | 320 | 410 | 410 |
| 6012-15 | 1200 | 600 | 150 | 32.5 | 20 | 10 | 250 | 450 | 450 |

** The given values are measured for unmounted force plates. Therefore, the actual value might be higher. Please refer to the "**Natural Frequency**" section below for a detailed explanation.*

For all force plates given in Table 5-1 the maximum error due to *linearity* or *hysteresis* is 0.2% of the full-scale output signal. Since the calibration matrix is already stored in the force plate all outputs are calibrated and corrected for any cross talk. Sensitivity for all force plates is 5V per rated output. Resolution of output signal is at least 0.02% of full scale. Finally, all force plates have an operating temperature range of 0-50 ºC.

[2] Technical specifications given in this chapter may be changed without notice and shall not be regarded as a warranty.

## Rated Load

The rated load given in Table 5-1 is the maximum dynamic load capacity that the force plate can measure within the linearity limit given above. Exceeding the rated load limit may cause the force plate to behave nonlinearly. The overload capacity for the force plates is 50%; i.e. they are designed to sustain loads up to 1.5 times the rated load without any damage.


**Exceeding the overload capacity will result in permanent deformation of the transducers, and damage the force plate. Moreover, localized, high impact forces are likely to cause physical damage to the force plate.**

## Natural Frequency

The natural frequency of the force plate is an important parameter for the studies where high impact forces are involved (e.g. running, impact landing, etc.). Impact forces are the source of band-limited excitation where the force might contain a wide range of frequencies. These frequencies are likely to excite fundamental structural modes of the force plate and might cause the output signal to be unstable. Table 5-1 lists the natural frequencies for the first structural mode of the force plates. For impact studies, it is recommended to have the natural frequency as high as possible. The natural frequency of the force plate is determined by *intrinsic* and *extrinsic* factors. Intrinsic factors are physical features such as the total mass, stiffness of the top, base and transducers. For Bertec force plates these physical features are optimized at the design stage to have a high natural frequency. Extrinsic factors, on the other hand, are related to operating conditions of the force plate. Type of mounting and condition of the mounting surface, for example, might lead to the natural frequency of the overall system to be different than those listed in Table 5-1.

The values given in Table 5-1 are determined so that they reflect the effect of intrinsic factors. These values are measured in an environment where the force plate is free to move in all directions (free boundary conditions). Adverse mounting conditions such as compliant foundations, non-flat mounting surfaces, or improper shimming will result in a lower natural frequency for the force plate. Using a mounting plate as described in section ***2.1 Mounting the Force Plate*** will result the natural frequency to be higher than the values listed in Table 5-1.


**Improper mounting of the force plate will lower the overall natural frequency of the system. Using a mounting plate on a stiff foundation will result in higher frequencies than those listed in Table 5-1.**

## Anchor Locations

Four anchor locations are provided on the force plate so that it can be fastened to a mounting plate or to the floor using standard ⅜”-16 (or M8-1.25) machine bolts. Standard mounting plates for each force plate model already have pre-drilled anchor locations with steel-threaded inserts. Figure 5.1 and Table 5-2 give the exact locations of the anchor points for standard force plates models.

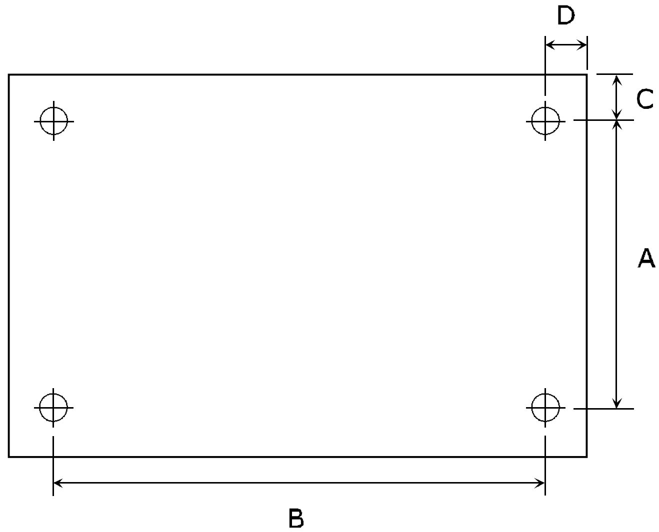



**Figure 5.1 –** Force plate anchor locations. For numerical values of A, B, C and D for different force plate models, please refer to **Table 5-2**.

**Table 5-2 –** Numerical values for A, B, C and D shown in **Figure 5.1**. All values are in mm.

| MODEL | A | B | C | D |
|---|---|---|---|---|
| 4060-08<br>4060-10<br>4060-15 | 342 | 552 | 29 | 24 |
| 4550-08 | 438 | 458 | 13 | 25 |
| 4060-NC | 342 | 552 | 29 | 24 |
| 4080-10<br>4080-15 | 342 | 752 | 29 | 24 |
| 6090-15 | 542 | 860 | 29 | 24 |
| 9090-15 | 758 | 860 | 71 | 20 |
| 6012-15 | 540 | 1113 | 30 | 44 |

# 5.3. Amplifiers and Signal Converters

Signal conditioning and amplification for the force plates are provided by means of external amplifiers. Each force plate has an internal digital preamplifier, which digitizes the analog signal from the transducer strain gauges, and conditions it through oversampling, preliminary amplification and filtering. The calibration matrix of the force plate is digitally stored on the preamplifier so that the output is already calibrated data having the units of Newtons and Newton-meters. The output of the force plate is a 16-bit digital signal using RS-485 format.

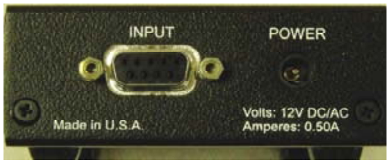
## AM6500 Digital Signal Converter

The **AM6500** series external converter transforms the digital output signal to USB format, which can directly be connected to the computer (see Figure 5.2) using a standard USB cable.


**Figure 5.2** – AM6500 USB converter

The input-output connections for the AM6500 module is shown in Figure 5.3 . The output is a standard female B-type USB connector. Next to the connector are two LED lights. The bottom light is on when the unit is powered via the transformer, and the top light comes on if the unit is connected to the USB port of the computer. The input to the module is via a 9-pin D-Sub connector located next to the power input.


(a)




(b)

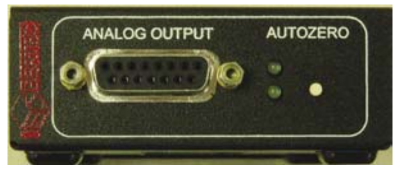
**Figure 5.3 – (a)** The USB output connector is a standard B-type connector. The lower light is on when the unit is connected to power, and the top light comes on when the unit is connected to the USB port of the computer. **(b)** The input to the module is through a 9-pin D-Sub connector located next to the power input.

## AM65XX Series Analog, Fixed Gain Amplifier

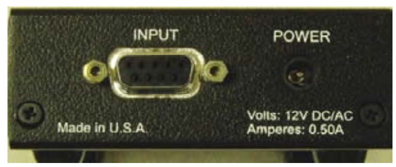
The **AM65XX** series external analog amplifiers are utilized to convert the digital output of the plate to an analog signal using a **fixed**, **pre-set** gain value. This pre-set gain value is indicated by the suffix XX in the model identifier (i.e. 6501 – unity gain, 6504 – gain of four, etc.). These amplifiers also provide an *auto zero* button to remove tare load offset (see Figure 5.4). An external, universal power supply is used to provide power to the amplifier.


**Figure 5.4** – AM65XX analog amplifier

The input and output connections to the AM65XX module are shown in Figure 5.5. The pin assignments for the analog output channels are given in Figure 5.9 below. The output voltage range for all channels is ±5V. Shorting pins 9 and 10 on the 15-pin output connector has the same effect as pushing the autozero button on the AM6501.




(a)




(b)

**Figure 5.5** – **(a)** The analog output from the AM65XX is supplied via a 15-pin D-Sub connector (see **Figure 5.9** for pin assignments). Next to the output connector is the autozero button and two LED's. The top LED is lit when the signal offset is removed through autozero. The bottom LED shows that the unit is connected to power. **(b)** The input to the module is through a 9-pin D-Sub connector located next to the power input.


**A blinking bottom LED indicates that the unit is not connected to a force plate. Please check the cable connecting the force plate to the unit.**

AM6504 has two additional dipswitches on the top surface to set the gain for the output signal. Each switch has a ON/OFF setting. The gains corresponding to each setting is given in the Figure below.

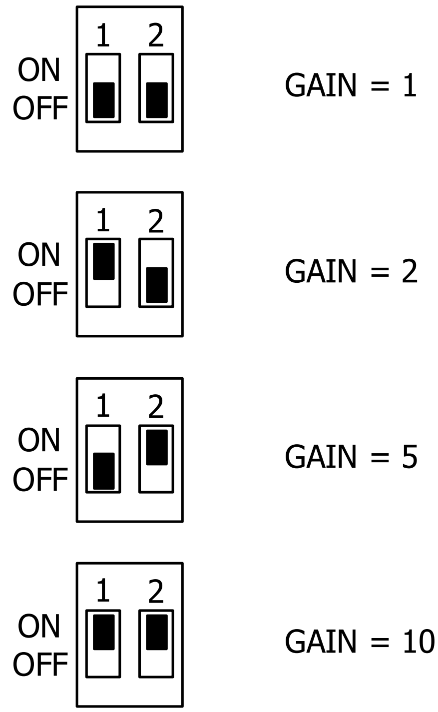



**Figure 5.6 -** Gain switch settings for the AM6504

## AM6800 Dual Output, Adjustable Gain Amplifier

The **AM6800** amplifier, shown in Figure 5.7, incorporates both analog and digital outputs into one unit. The gain of the analog output is user selectable, and has 7 different settings (1, 2, 5, 10, 20, 50, 100). A single gain selection switch is provided for all 6 output channels (see Figure 5.8 (a)). A three-digit LED display on the front panel shows the current gain setting. The channel signal indicators show the polarity of the analog output for the six force plate channels. The *auto zero* button is utilized to remove tare load offset from each channel output. The mains power input is a universal input with the range 100-240 V, 50-60 Hz (Figure 5.8 (b)). The digital output is a USB signal.

If the unit is not connected to a force plate, the digital display will read "**PL7**". After the force plate is properly connected to the unit, when the amplifier is turned on, the display will briefly (about 0.5 sec.) show the message "**CAL**", which indicates that the amplifier has successfully recognized the force plate. Finally, the gain setting will display on the digital readout. The pin assignments for the analog output channels are given in Figure 5.9 below.


**Figure 5.7 –** AM6800 dual output, variable gain signal amplifier with auto zero.


(a)


(b)

**Figure 5.8 – (a)** Front panel of AM6800 amplifier. Of the two lights between the auto zero button and power switch the bottom one comes on when the unit is switched on, and the top light is lit after the auto zero button is pressed. **(b)** The input and output to the unit is through 9-pin and 15-pin female D-Sub connectors respectively.

A 19" rack mounting adaptor for AM6800 amplifier is available upon request from Bertec Corporation.

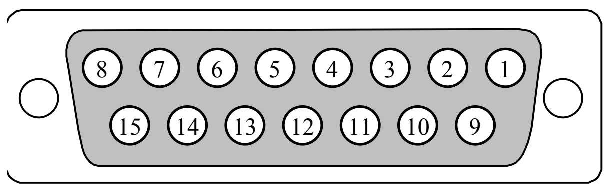
# General Specifications

The AM65XX series and AM6800 amplifiers provide a ±5 V full-scale calibrated analog output per rated load range for each of the six force plate channels. For example, if the force plate has a ±10 kN load range for the $F_z$ channel, then for a gain of unity, the –5.00 V output corresponds to –10 kN, and +5.00 V stands for +10 kN (i.e. a sensitivity of 0.5 mV/N). The analog gain used in data acquisition represents a trade-off between maximum load range and force plate sensitivity. If the same force plate above is used with an amplifier gain of 5, then the load range will be limited to ±2 kN. This means the plate now has an increased sensitivity of 2.5 mV/N. The analog load scale factors for specific force plates, given on the product data sheet supplied with the force plate are specified for a gain of one.

The analog output signals are filtered so that they have a standard bandwidth of 500 Hz. The actual analog gain ratios are applied to the digital signal with an accuracy of 99.997%.

The *auto zero* button removes the signal offset and sets the analog output signal within ±5 mV. This feature can be used to increase the useful measurement range of the force plate by shifting the signal baseline. Note that *auto zero* might not set the mean value of the signal to true zero. Therefore, an additional offset removal through software is suggested.

The digital input to all external amplifiers and signal converters is a female 9-pin D-Sub connector, whereas the analog output is in the form of a female 15-pin D-Sub connector with the pin assignments shown in Figure 5.9. Shorting pins 9 and 10 has the same effect as pushing the autozero button on the AM6501 and AM6800.




CH1 : Pin 3
CH2 : Pin 4
CH3 : Pin 5
CH4 : Pin 6
CH5 : Pin 7
CH6 : Pin 8
GRND : Pin 10
Autozero: Pin 9

**Figure 5.9 –** Pin configuration for the standard analog 15-pin female D-Sub connector for the AM65XX and AM6800 amplifiers. The output range for each channel is ±5V. Shorting pins 9 and 10 has the same effect as pushing the autozero button.