Measurement of the Hand Transmitted Vibration of the Human Hand Arm System During Operation of a Hand Tractor
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4
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26
27 **SUMMARY:**
28 Here, we present a standardized method for measurement of the hand transmitted vibration
29 from handles of a single-axle tractor with special reference to changes in grip force and
30 vibration frequency.
31
32 **ABSTRACT:**
33 Operators of hand tractors are exposed to high levels of hand transmitted vibration (HTV). This
34 vibration, which can be both irksome and hazardous to human health, is imparted to the
35 operator via his or her hands and arms. However, a standardized method for measuring HTV of
36 hand tractors has yet to be defined. The aim of the study was to present an experimental
37 method for the investigation of the biodynamic response and vibration transmissibility of the
38 hand-arm system during the operation of a hand tractor in a stationary mode. Measurements
39 were performed with ten subjects using three grip forces and three handle vibration levels to
40 examine the influences of the hand pressure and frequency on hand transmitted vibration
41 (HTV). The results indicate that the tightness of grip on the handle influences the vibration
42 response of the hand-arm system, especially at frequencies between 20 and 100 Hz. The
43 transmission of lower frequencies in the hand-arm system was relatively unattenuated. In
44 comparison, attenuation was found to be quite marked for higher frequencies during the

45 operation of the hand tractor. The vibration transmissibility to different parts of the hand-arm
46 system decreased with the increase of the distance from the vibration source. The proposed
47 methodology contributes to the collection of consistent data for the evaluation of operator
48 vibration exposure and the ergonomics development of hand tractors.
49
50 **INTRODUCTION:**
51 Hand tractors, also known as power tillers, are widely used in developing countries for the land
52 preparation of small fields. The field operation of a hand tractor involves walking behind the
53 machine and holding its handles to control its movement. The operators of hand tractors are
54 exposed to high levels of vibration, which could be attributed to the small single cylinder engine
55 and lack of suspension system of hand tractors[1]. The hand-arm vibration syndrome (HAVS)[2] can
56 be caused by long-period endurance from the vibration, named hand transmitted vibration
57 (HTV), which generated by the hand tractor and received by the operator's hands. To assess the
58 health risks derived by operators' exposure to the HTV of hand tractors, it is necessary to
59 establish a method for the measurement of the vibration response of the hand-arm system.
60
61 The hand-arm system is composed of bones, muscles, tissues, veins and arteries, tendons and
62 skin[3], and the direct measurement of HTV poses many problems. The relevant international
63 standards[4,5] provide guidelines pertaining to the measurement of the severity of vibration
64 generated in the immediate vicinity of the hand, including the coordinate system for the hand,
65 the location and mounting of accelerometers, the measurement duration, cable connector
66 problems, *etc*. However, the standards do not take into consideration intrinsic variables, such
67 as the grip force, the posture of the hand and arm, individual factors, *etc*. These factors have
68 been examined extensively under a wide range of vibration excitations and test conditions[6-13],
69 but the results of different investigators are not in good agreement. Many of these factors have
70 not been sufficiently understood to be incorporated into standard methods. This restriction is
71 partially attributable to the complexities of the human hand-arm system, the test conditions,
72 and the differences in the experimental and measurement techniques employed.
73
74 Moreover, most of the earlier measurements of HTV were performed under carefully controlled
75 conditions with idealized vibration excitations, grip force, and postural conditions. The findings
76 and experimental procedures of these measurements, therefore, may not truly replicate real-
77 world conditions, such as the operating conditions of hand tractors. Moreover, only limited
78 efforts have been undertaken to study the HTV of hand tractors with field measurements.
79 These measurements were performed using accelerometers attached to the operator's wrist,
80 arm, chest, and head to measure the whole body vibration under the tractor's transportation
81 conditions[1], or under the conditions of tilling in an untilled field and puddling in a submerged
82 field with different levels of engine speeds[14]. The effect of the grip force, which could be a
83 crucial factor of HTV[7,8], was not isolated. These methods are therefore unsuitable as
84 standardized measurement procedures due to the operator's various forced postures during
85 farming ascribed to the harsh environmental conditions.
86
87 The present research was undertaken to contribute to the establishment of reliable and
88 repeatable procedures for the HTV measurement of hand tractors in a stationary mode. **Figure**

1 presents the schematic diagram of the experimental design. A hand tractor manufactured in China and commonly used by Chinese farmers was employed, and ten research workers were chosen as subjects for the study. Seven lightweight piezoelectric accelerometers attached to the tractor-hand-arm system were used to measure the vibration. One tachometer and two thin-film pressure sensors monitored the engine speed and grip force during testing. The subjects were required to sequentially operate the hand tractor at specified engine speeds and with specified grip forces to obtain the vibration characteristics in various operational modes. This manuscript provides a detailed protocol for the HTV measurement of the tractor-hand-arm system with unique consideration of changes in the grip force and vibration frequency.

PROTOCOL:

All procedures were approved by the Ethics Committee of Chongqing University of Technology and each subject provided written informed consent prior to participation in this study.

1.   Hand tractor preparation

1.1.   Ensure the hand tractor is subjected to proper test conditions with a full fuel tank, without looseness of bolts, and without other mechanical defects that would result in abnormal vibration.

NOTE: The specifications of the hand tractor used in this experiment are given in **Table 1**.

1.2.   Place the hand tractor in a test site with a dry, firm, and level ground surface.

NOTE: If this experiment was conducted in an indoor laboratory, the laboratory must be well-ventilated to prevent any injurious effects of the exhaust gas from the hand tractor.

1.3.   Remove the dust cover of the engine pulley to conveniently calibrate the engine speed with a speedometer during the experiment.

1.4.   Remove the elastomeric materials of the handles according to ISO 5349-2 standard[5].

2.   Subject preparation

2.1.   Ensure that all subjects are healthy with no physical ailment and are above the age of 18 years[3]. Inform each subject about the study objectives and test procedures. Obtain written informed consent from all subjects.

2.1.1.   Exclude subjects with the following diseases: primary Raynaud's disease or secondary Raynaud's phenomenon, impairment of blood circulation to the hands, deformity of bones and joints, disorders of the peripheral nervous system or musculoskeletal system[3].

2.2.   Ask subjects to wear sleeveless or short-sleeved clothing, and to remove watches,

133 bracelets, rings, *etc*.

134

135 2.3.   Warn each subject not to touch the gear shift lever of the hand tractor during operation.
136 Warn each subject to stay away from the engine pulley when the hand tractor is running.

137

138 2.4.   Provide subjects with speed regulation training on the hand tractor. Inform each subject
139 to shut down the engine at the end of the experiment by pressing down on the engine switch
140 button.

141

142 NOTE: Generally, the engine speed regulation is controlled by the throttle switch located on the
143 right handle, and subjects are trained to regulate the engine speed by turning the throttle
144 switch to the left (speed decrease) or to the right (speed increase) with their right hands.

145

146 2.5.   Instruct each subject how to operate the hand tractor and how to regulate the engine
147 speed from 1500 rpm to 3500 rpm.

148

149 2.6.   Measure each subject's body dimensions (standing height, mass, forearm length, upper
150 arm length, hand length).

151

152 NOTE: **Table 2** summarizes the physical characteristics of ten healthy subjects in this
153 experiment.

154

155 2.7.   Wrap the accelerometer adapters tightly on the hand and arm of each subject at the
156 locations indicated in **Figure 2**.

157

158 NOTE: Each adapter was fabricated using a nylon strap and a piece of the galvanized iron sheet
159 (0.3 mm) to provide a rigid and light attachment.
160

161 **3.   Measurement system setup**

162

163 3.1.   Acceleration measurement system setup

164

165 NOTE: The present steps aim to collect the vibration acceleration signals from the handle of the
166 hand tractor and six locations of operator's hand-arm system. The proposed approach employs
167 a compact Data Acquisition (DAQ) system composed of seven accelerometers, three data
168 acquisition cards, a DAQ chassis, a laptop computer, and some associated cables (**Figure 3**).
169 Other types of DAQ systems with proper characteristics for the involved application can be
170 similarly applied.

171

172 3.1.1.   Before initiating a measurement, gather all the components of the measurement system
173 (accelerometers, data acquisition system, thin-film pressure sensing system, tachometer, digital
174 goniometer, and other relevant components).

175

176 3.1.2.   To set up the acceleration measurement system, connect the accelerometer with the

177 data acquisition cards using the accelerometer cables. Using an Ethernet cable, connect the
178 chassis with the computer.

180 NOTE: Two tri-axial accelerometers and five single-axis accelerometers fixed with magnetic
181 mounting base were used in this experiment.

183 3.1.3. Attach one tri-axial accelerometer on the left handle of the hand tractor and attach the
184 other one on the accelerometer adapter of the subject's hand. Attach single-axis
185 accelerometers, one by one, on the accelerometer adapters of the subject's arm and shoulder.

187 NOTE: The locations of the accelerometers are as shown in **Figure 1.** The location selection of
188 the tri-axial accelerometer on the left handle of the hand tractor should be as close to the
189 operator's left hand as possible.

191 3.1.4. Adjust the orientation of the tri-axial accelerometers on the hand to be consistent with
192 the basicentric coordinate system (**Figure 4**) for measurement of hand-arm vibration refer to
193 ISO 5349-1 standard[4]. Using adhesive tape, secure the accelerometer cables on the skin surface
194 of the subject's arm and the tractor's handlebar.

196 3.2.   Grip force measurement setup

198 NOTE: A thin-film pressure sensing system[15,16] was designed with two resistive pressure
199 sensitive sensors, a single-chip controller, and an LED display, and was calibrated before
200 measurement, as shown in **Figure 5**.

202 3.2.1. Attach two thin-film sensors symmetrically on opposite sides around the central axis of
203 the handle using double-sided adhesive tape.

205 3.2.2. Place the screen of the sensing system at a convenient height so that the subject could
206 monitor and adjust the grip force to the specified level during the operation of the hand tractor.

208 3.3.   Engine speed measurement setup

210 NOTE: Engine speed refers to the revolutions per minute (RPM) of the propeller of the
211 employed hand tractor engine, which equals to the RPM of the engine pulley. A laser
212 tachometer was used to calibrate and monitor the engine speed during operation.

214 3.3.1. Attach a piece of retroreflective tape (approximately 10 $\times$ 10 mm) to the engine pulley
215 surface for laser tachometer measurement.

217 3.3.2. Place the tachometer at a proper height and perpendicular to the retroreflective tape.

219 3.4.   Posture measurement
220

221   3.4.1. Instruct the subject to hold and raise the handle to a horizontal position. Measure the
222   subject's hand and arm posture using a digital goniometer.
223
224   NOTE: The five angles[17] used to describe the hand and arm posture during the operation of the
225   hand tractor are shown in **Figure 6.** The subjects' posture angles measured in this experiment
226   are presented in **Table 2.**
227
228   3.4.2. Ask the subject to maintain the posture until the end of the trial.
229

230   **4.   Experiment and data acquisition**

231
232   4.1.   Start the hand tractor in neutral and keep it running at a low engine speed (around 1500
233   rpm) for about 30 s until it stabilized.
234
235   4.2.   Turn on the tachometer, the thin-film pressure sensing device, the laptop computer and
236   the acceleration data acquisition system, respectively.
237
238   4.3.   Open the DAQ software and create a new file for each subject. Set the parameters of
239   acceleration, acquisition mode, and sampling rate for data collection.
240
241   NOTE: To obtain the accurate characterization of the HTV, the sampling rate should be no less
242   than 1500 Hz. In this study, the sampling rate was set at 1650 Hz. If a more higher sampling rate
243   was used for data collection, a low-pass filter with a cut-off frequency at 1500 Hz was advised
244   to remove the noise influences such as the irrelevant high-frequency contributions.
245
246   4.4.   Click the **Run** and wait about 10 s until the system is stabilized. Then click **Record** to
247   start recording the acceleration data.
248
249   4.5.   Adjustment of the engine speed and grip force
250
251   NOTE: As shown in **Figure 7**, this experiment was conducted at three levels of engine speed
252   (1500, 2500 and 3500 rpm) and three levels of grip force (20, 30, and 40 N) during each trial.
253   The approximate duration of each subject's HTV testing is 6 min.
254
255   4.5.1. Ask the subject to monitor the tachometer and adjust the engine speed to 1500 rpm
256   until it stabilized.
257
258   4.5.2. Instruct the subject adjust the grip force carefully to 20 N by looking at the displayed
259   force signals from the thin-film pressure sensing system, and keep this grip force level for about
260   30 s.
261
262   NOTE: The adjustment of the grip force denotes the increase or decrease of pressure between
263   the hand and the handlebar of the hand tractor. Subjects should perform the adjustment of the
264   grip force through holding the handlebar more tightly or lightly.

265

266 4.5.3. Adjust the grip force to 30 N and keep about 30 s. Then, adjust the grip force to 40 N
267 and keep about 30 s.

268

269 4.5.4. Adjust the engine speed to 2500 rpm and repeat steps 4.5.2 and 4.5.3.

270

271 4.5.5. Adjust the engine speed to 3500 rpm and repeat steps 4.5.2 and 4.5.3.

272

273 4.6.   Ask the subject to turn the throttle switch to the lowest engine speed. Put down the
274 handle and shut down the engine of the hand tractor.

275

276 4.7.   Save the data and shut down the DAQ system. Remove and place the accelerometers on
277 the next subject.

278

279 4.8.   Repeat steps 4.3 to 4.7 until the end of the data collections of all subjects.

280

281 4.9.   Export the acceleration time-series data for further analysis.

282

283 **5.   Data processing and analysis**

284

285 5.1.   Import the recorded vibration time domain signals to MATLAB software. Calculate the
286 root-mean-square (RMS) values of the vibration acceleration of hand tractor's handle, which
287 represent the vibration exposure during the operation of the hand tractor, with the Equation
288 (1):

289

290 $$a_{RMS} = (\frac{1}{T} \int_0^T a(t)^2 dt)^{0.5} \ (1)$$

291

292 where, a_{RMS} is the RMS of vibration acceleration (m/s²) calculated for each 1/3rd octave band,
293 $a(t)$ is the measured vibration acceleration amplitude (m/s²), and T is the duration of the
294 measured vibration acceleration (s).

295

296 NOTE: In ISO 5349-1 standard, it is important to use RMS acceleration to represent the
297 magnitude of vibrations transmitted to the operator's hands.

298

299 5.2.   Calculate the RMS values of vibration acceleration on hand, wrist, arm and shoulder of
300 each subject using Equation (1). Calculate the vibration transmissibility (TR) using Equation
301 (2)[1,14]:

302

303 $$TR = a_{out} / a_{in} \ (2)$$

304

305 where, a_{in} is the handle vibration for HTV, and a_{out} is the respective vibration in the six
306 locations of the subject's hand-arm system (see **Figure 2**).

307

308 NOTE: According to ISO 5349-1, the factors (except for grip force and vibration frequency) may
309 influence the results of hand transmitted vibration measurement include: the operator's skill,
310 body posture, climatic conditions, noise, *etc.* To decrease these random factors, the TR values
311 of all the measurement locations of the ten subjects in this study were averaged.

312

313 5.3. Convert the time domain signals of the handle to frequency domain signals by fast
314 Fourier transform (FFT) algorithm using MATLAB program to examine the input vibration.

315

316 **REPRESENTATIVE RESULTS:**
317 The experiment was carried out in the laboratory (air temperature 22.0 °C ± 1.5 °C) on ten
318 healthy subjects (**Table 2**) during the operation of a hand tractor in a stationary condition.

319

320 Following the protocol, vibration acceleration data were collected from the handle of the hand
321 tractor, as well as the back of the hand, the wrist, the arm, and the shoulder of each subject.
322 The spectrum of the vibration acceleration occurring at the handle (input to the hand) was
323 obtained. **Figure 8** displays samples of the time domain and RMS frequency domain
324 accelerations on the handle at the engine speed level of 3500 rpm for a given time duration. It
325 is evident that the vibration acceleration was the highest along the *Y*-axis and the lowest along
326 the *X*-axis. The maximum accelerations of the *X* and *Z* directions occurred at the frequency of
327 58 Hz (which is the working frequency of the engine corresponding to the rotational speed of
328 3500 rpm). Most of the vibration energy was found to be centralized in the frequency range
329 from 50 to 200 Hz. With the same analytical process, the characteristics of both the time
330 domain and frequency domain signals could be obtained, such as the vibration amplitude, peak,
331 dominant frequency, *etc.*

332

333 The influences of the grip force and engine speed on the vibration response of the hand-arm
334 system were also examined. As shown in **Figure 9**, it was observed that the increase in the grip
335 force increased the vibration acceleration notably at frequencies between 20 and 100 Hz, and
336 three resonance frequencies (20, 40, and 80 Hz) were found to increase almost linearly with the
337 increase of the grip force. This is attributed to the increase of the contact stiffness and joint
338 stiffness[18,19]. These findings indicate that the presented measurement and adjustment methods
339 of the grip force could be effectively applied to HTV measurement.

340

341 As shown in **Figure 10**, this experiment examined the effect of the input frequency on HTV via
342 engine speed adjustment at three levels (1500, 2500, and 3500 rpm). At the location of the
343 back of the hand (**Figure 10A**), a higher value of acceleration was obtained at 3500 rpm
344 compared to lower engine speeds. In contrast, at the upper arm and shoulder (**Figure 10D**, **E**,
345 and **F**), the peak acceleration occurred at 1500 rpm. Through the comprehensive comparison of
346 both the locations and exciting frequencies, it is reasonable to conclude that lower frequencies
347 were transmitted relatively unattenuated in the hand-arm system, while attenuation was quite
348 marked for higher frequencies. Thus, most of the vibration energy was dissipated in the hand
349 and forearm.

350

351 **Figure 11** presents the averaged transmissibility to the back of the hand, forearm, upper arm
352 and shoulder from the ten subjects that are with engine speed of 2500 rpm and grip force of 30
353 N. It was found that the transmissibility to the different parts of the hand-arm system
354 decreased with the increase of the distance from the vibration source. The highest
355 transmissibility was observed at the back of the hand (location 1), with a peak value of 5.1 at
356 around 80 Hz. The amplification of vibration may be due to the resonance of the skin at the
357 metacarpal[20,21]. Consistent with the findings of previous studies[22,23], the resonant frequency of
358 the wrist (location 2) and elbow (location 4) transmissibility was around 20 Hz, with a
359 magnitude of approximately 3.0. Additionally, the shoulder (location 6) transmissibility peak
360 was 1.1 at around 10 Hz. It was also found that only vibrations of less than 25 Hz were
361 effectively transmitted to the forearm, upper arm, and shoulder. With Equation (2) in section
362 5.2 and following the analytical process of the transmissibility, it is feasible to examine the
363 influences on transmissibility with different exciting frequencies and changing grip force, and a
364 reasonable suggestion of operating hand tractor for farmers could be made.
365
366 **FIGURE AND TABLE LEGENDS:**
367 **Table 1 Specifications of the hand tractor.**
368
369 **Table 2. Subject physical characteristics.**
370
371 **Figure 1. The experimental protocol and data acquisition set up.** This example depicts a single
372 trial (from right to left) for the measurement of a subject's body dimensions, the wearing of 6
373 accelerometer adapters, the operating posture of the hand tractor, and the data acquisition set
374 up for the acceleration, grip force, and engine speed.
375
376 **Figure 2. The locations of the accelerometer adapters.** 6 accelerometer adapters were
377 wrapped in the locations of back of the hand, distal end of the forearm, proximal end of the
378 forearm, distal end of the upper arm, proximal end of the upper arm and the acromion along
379 the hand-arm system.
380
381 **Figure 3. Vibration measurement instrumentation.** The components of the measurement
382 system including accelerometers, data acquisition system, thin-film pressure sensing system, a
383 tachometer, a digital goniometer and other relevant components (computer, accelerometer
384 adapters, cables, tape measure, thermometer).
385
386 **Figure 4. The basicentric coordinate system for hand-arm vibration measurement.** The *X*-axis
387 is defined parallel to the longitudinal axis of the grip. The *Y*-axis is directed along the third
388 metacarpus bone of the hand. The *Z*-axis is perpendicular to the palm surface area.
389
390 **Figure 5. The thin-film pressure sensing system.** This system consists of two thin-film sensors, a
391 single-chip controller, and an LED display to show the real time grip force. The test data can also
392 be exported to a computer by the serial communication.
393
394 **Figure 6. The five angles used to describe the hand and arm posture.** *α* describes the shoulder

395 horizontal abduction, β describes the shoulder vertical abduction, γ identifies the elbow
396 extension, ϑ characterizes the wrist extension, and ω identifies the wrist deviation.
397
398 **Figure 7. Adjustment of the engine speed and grip force during the experiment.** The blue bars
399 represent different grip forces of 20, 30, and 40 N. The red lines indicate adjustment of engine
400 speed from 1500, 2500 to 3500 rpm. Therefore, there are 9 test cases from 1500 rpm, 20 N to
401 3500 rpm, 40 N. The duration of each test case is about 30 s.
402
403 **Figure 8. Samples of the time domain wave and amplitude spectra of the accelerations on**
404 **handle at the engine speed of 3500 rpm.** (A) The time domain wave and (B) amplitude spectra
405 in the X direction; (C) the time domain wave and (D) amplitude spectra in the Y direction; (E)
406 the time domain wave and (F) amplitude spectra in the Z direction.
407
408 **Figure 9. The mean relationship between the grip force and RMS vibration acceleration**
409 **measured at six locations of the hand-arm system of ten subjects:** (**A**) back of the hand; (**B**)
410 distal end of the forearm; (**C**) proximal end of the forearm; (**D**) distal end of the upper arm; (**E**)
411 proximal end of the upper arm; (**F**) acromion.
412
413 **Figure 10. The mean relationship between the engine speed (frequency) and RMS vibration**
414 **acceleration measured at six locations of the hand-arm system of ten subjects:** (A) back of the
415 hand; (B) distal end of the forearm; (C) proximal end of the forearm; (D) distal end of the upper
416 arm; (E) proximal end of the upper arm; (F) acromion.
417
418 **Figure 11. Vibration transmissibility at the 1/3rd octave band at different locations in the**
419 **hand-arm system at the engine speed of 2500 rpm and grip force of 30 N.** The 6 curves
420 represent the TR values from back of the hand (location 1) to the acromion (location 6) as
421 shown in the legend. The dashed line is a dividing line of vibration amplification (above this line)
422 and vibration attenuation (below this line).
423
424 **DISCUSSION:**
425 The protocol presented in this study was established based on HTV standards[4,5,24], and was
426 developed as the standard steps for the measurement of the HTV of the human hand-arm
427 system during the operation of a hand tractor in a stationary condition. This condition is the
428 most stable state of the hand tractor to help ensure the reliable measurement of the vibration
429 actually transmitted to the hand and arm. The range of variables considered to perform the
430 test, via the adjustment of the engine speed and grip force, covers the normal and safe
431 operating range of the hand tractor. Considering the complexity of the hand-arm system, the
432 experimental results yielded from this protocol were found to agree well with data reported in
433 articles on the characteristics of vibration sources[25], vibration transmissibility[1,26], and the
434 essential factors[8,27] that affect the response of the hand-arm system during the operation of
435 hand tractors.
436
437 The results are dependent on some critical components of this setup within the protocol. First,
438 because the weight of the accelerometer affects the magnitude of the vibration of the hand-

439 arm system[20], the total weight of the accelerometer and adapter should be as light as possible
440 to reduce measurement errors. Second, each accelerometer adapter should be tightly secured
441 on the hand-arm system to prevent any relative motion between the measurement point and
442 the accelerometer. Third, the test trial of each subject should be completed without
443 interruption to reduce the effect of the operating posture.
444
445 The main limitation of this study is that the vibration transmissibility to the hand-arm system
446 was only measured and analyzed in the *Z*-axis direction (**Figure 4**) due to the use of single-axis
447 accelerometers at the locations of arm and shoulder. Although flexible and thin-film sensors
448 were used to measure grip force during the test, further measurement efforts along the shear
449 direction are expected to provide considerable insights into the characterization and
450 assessment of HTV, which represents another limitation of the present study. Additionally, the
451 intrinsic factors of operators, such as their body size, body posture, and hand and arm size,
452 influence HTV. As a subsequent step, more data will be collected to examine these factors using
453 the presented protocol.
454
455 This protocol will be helpful for the understanding of the vibration transmission characteristics
456 of the hand tractor-hand-arm system. The main potential applications of the proposed
457 methodology are the estimation of human-tractor interaction phenomena, the ergonomics
458 development of hand tractors, and the development of protective devices such as isolators and
459 gloves.
460

470 **DISCLOSURES:**
471 The authors have nothing to disclose.
472

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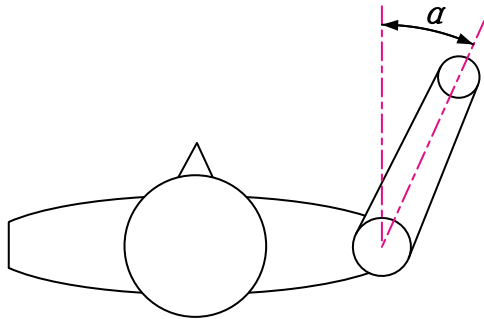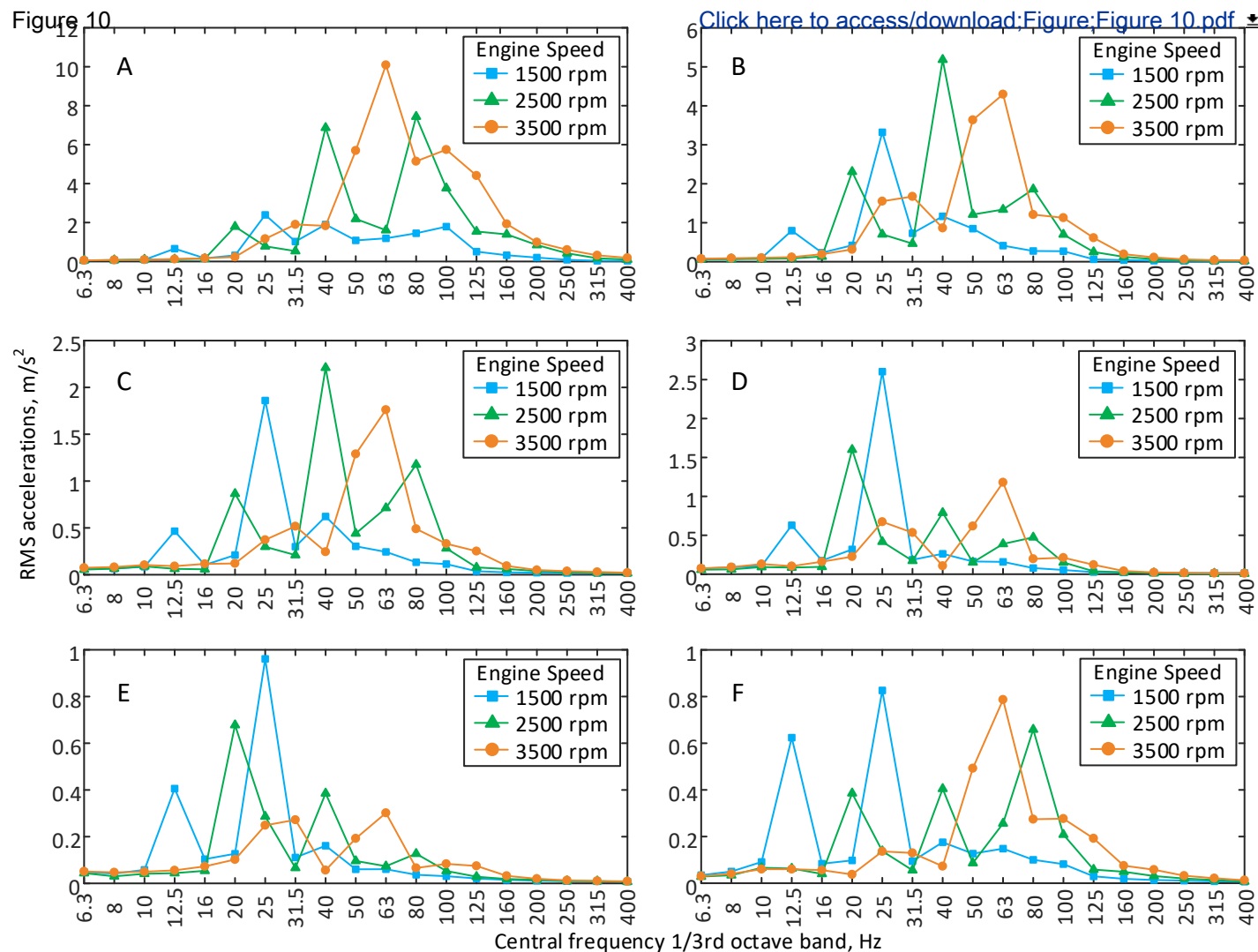546

Figure 1

Click here to access/download;Figure;Figure 1.pdf ⬇

Reflective sticker
Accelerometer
Accelerometer adapter

Laptop computer
Data acquisition system
LED display
Single-chip controller
Engine pulley
Tachometer

Hand tractor operation
Connecting accelerometers
Thin-film pressure sensors

Wearing adapters

Body dimension measurement
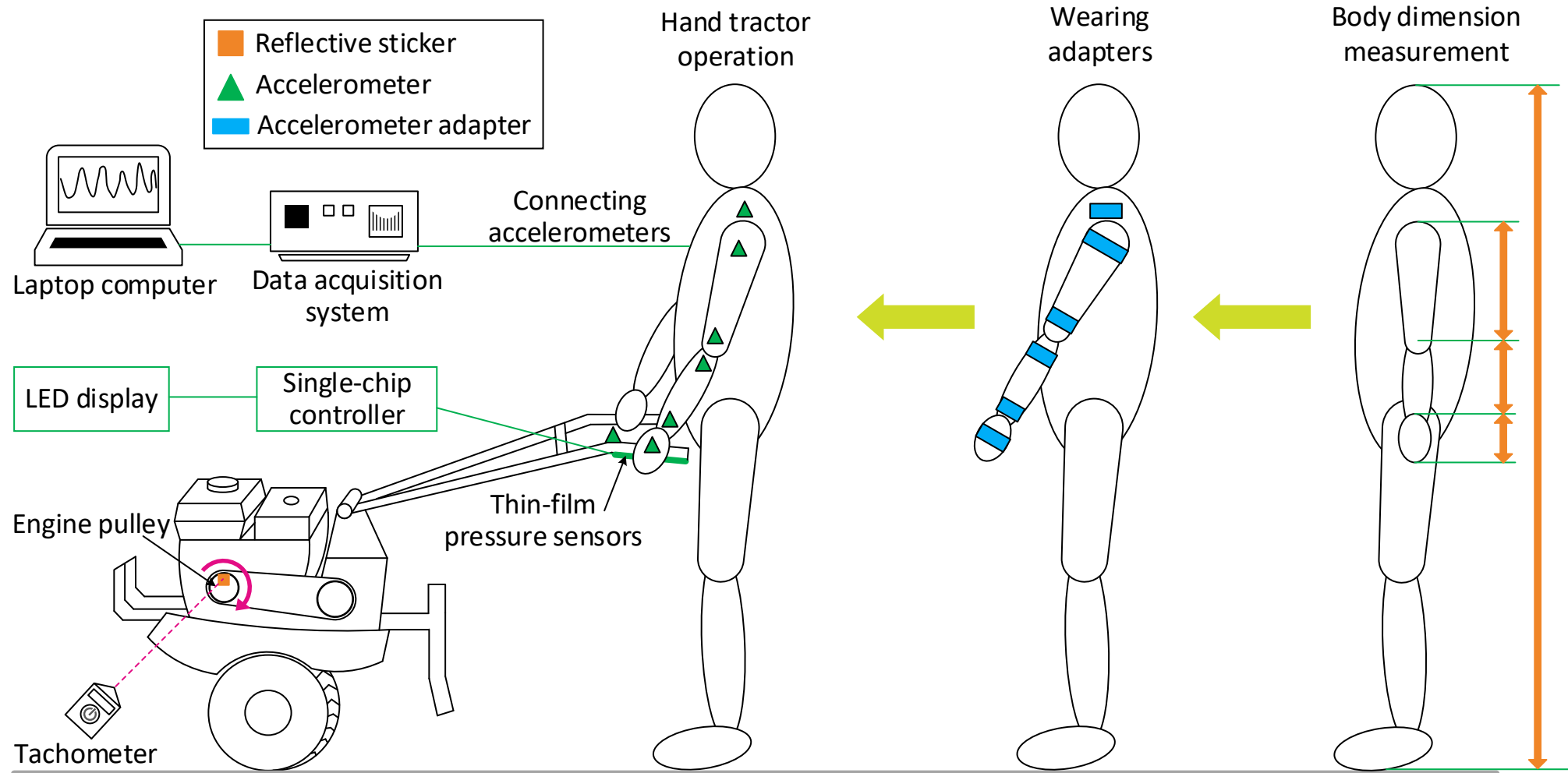
Figure 2

Acromion
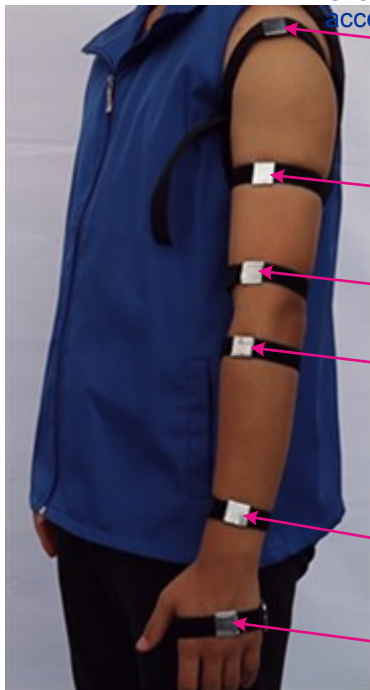
Proximal end of upper arm

Distal end of upper arm

Proximal end of forearm

Distal end of forearm

Back of the hand

Figure 3

Accelerometers

Data acquisition card

DAQ chassis
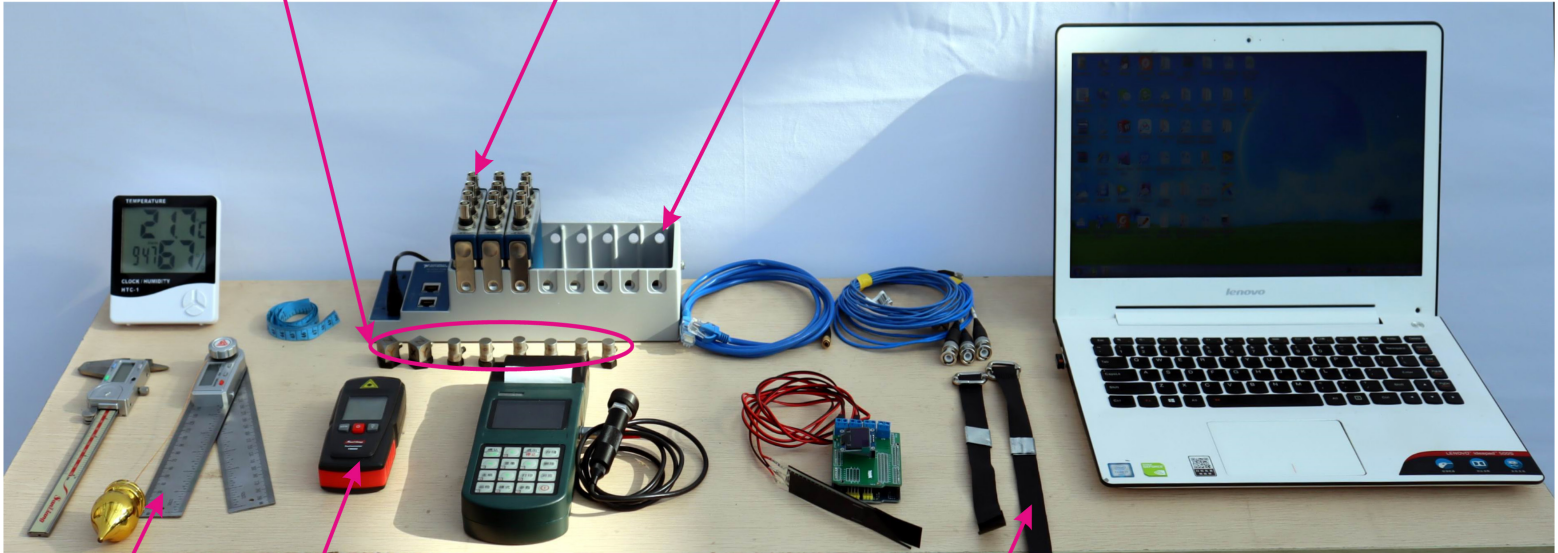
Digital goniometer

Tachometer

Accelerometer adapter

Figure 4
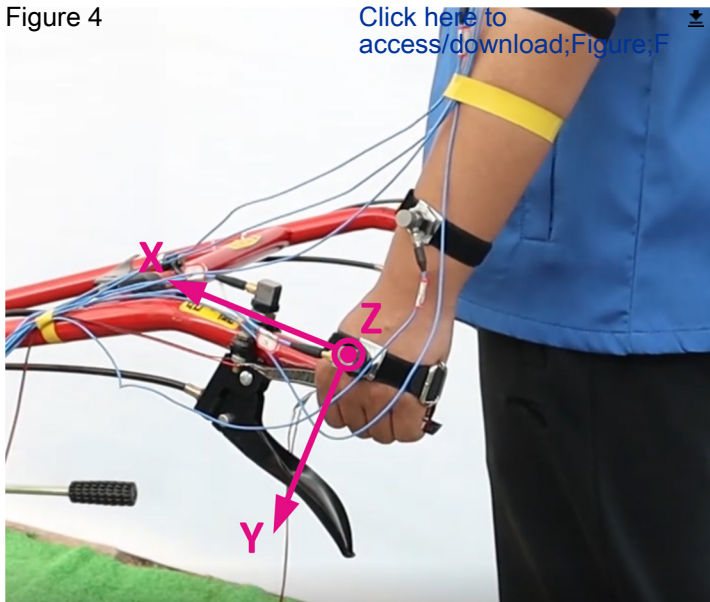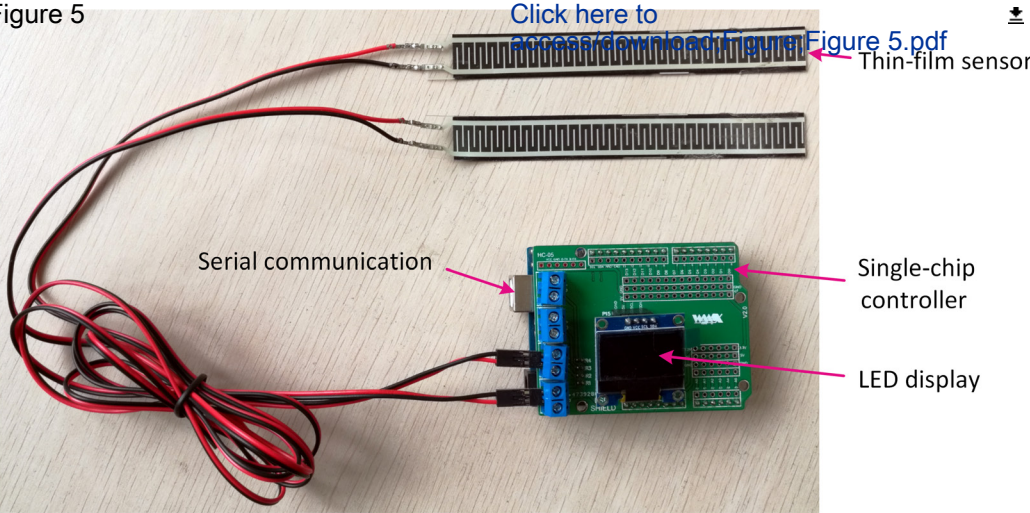
Figure 5

Click here to access/download Figure Figure 5.pdf

Thin-film sensor

Serial communication

Single-chip controller

LED display
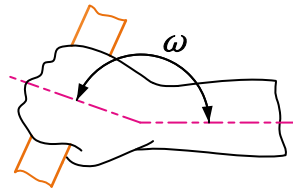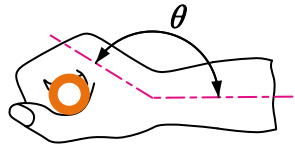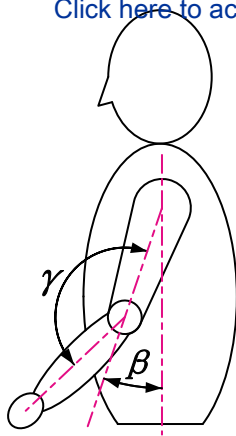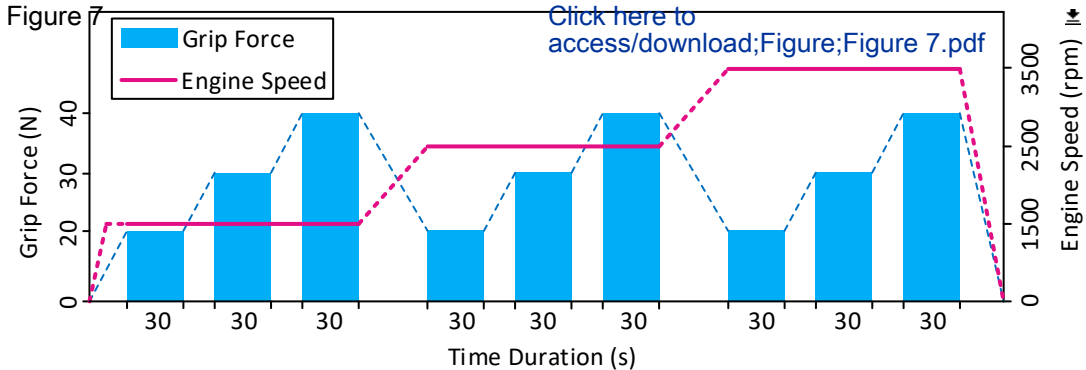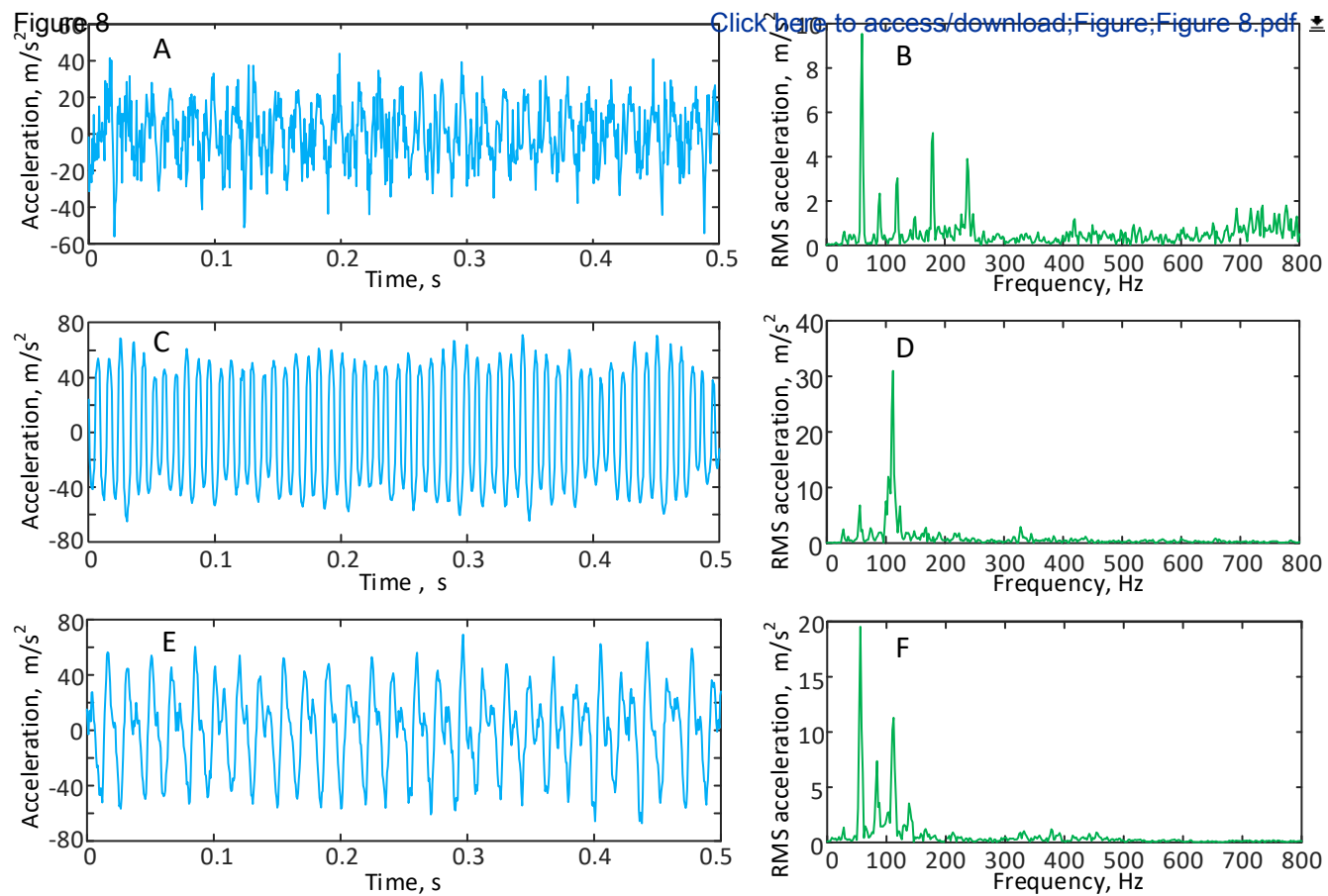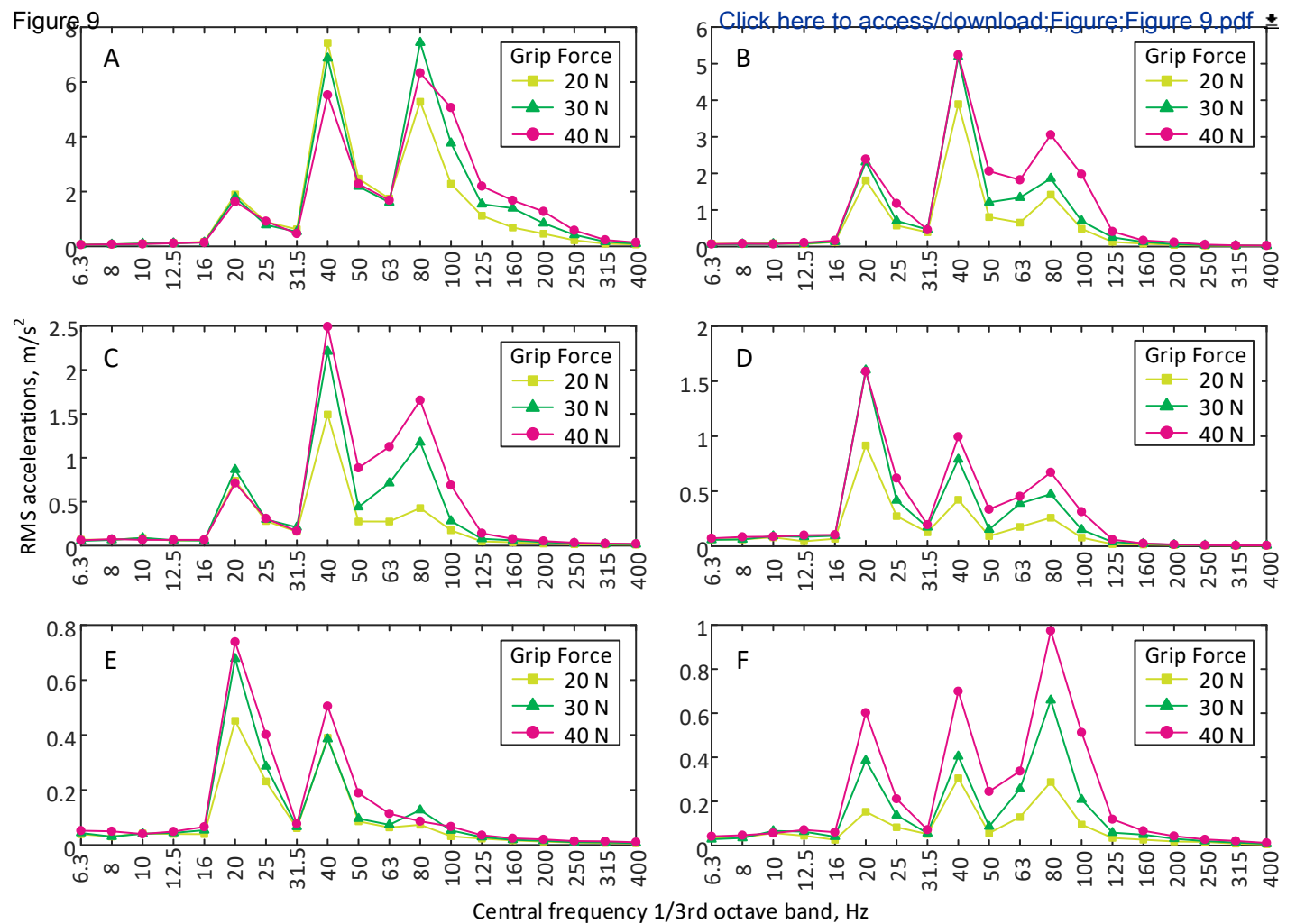
Figure 6

Figure 7

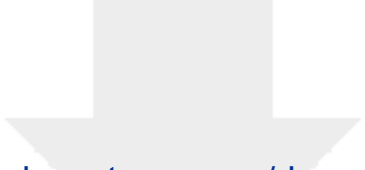Figure 8

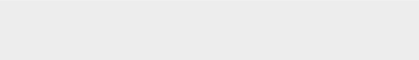Figure 9

Figure 9

Figure 10
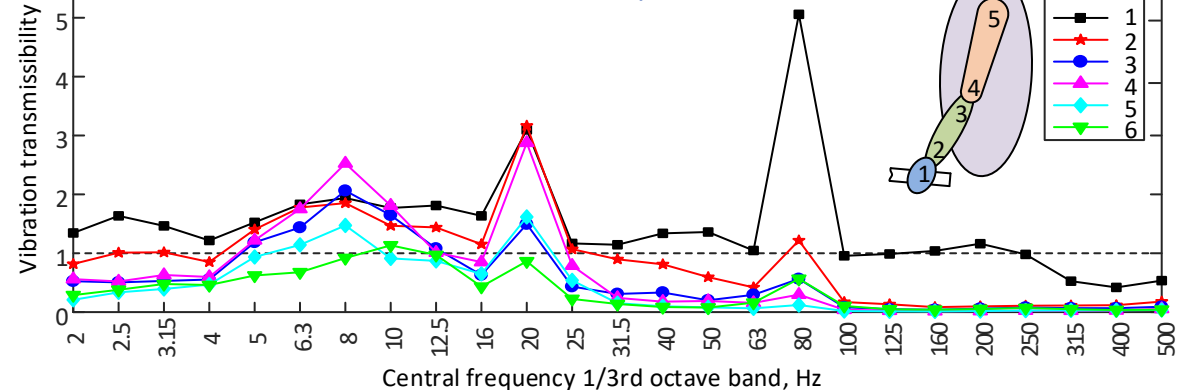
Table 1

Table 1. Specifications of the hand tractor.	
Engine model and type	JUWEI FC 170, gasoline, single cylinder, four-stroke, OHV, forced-air cooled
Swept volume, cc	208
Rated power, kW	4.0 kW at 3600 rpm
Maximum Torque, Nm/rpm	12/2500
Number of speeds	2 forward, 1 reverse
Start mode	Recoil start (pull start)
Dry weight of engine, kg	19
Weight of hand tractor with full fuel tank, radiator and lubricating oils, kg	72
Tyre type	Rubber wheel
Tyre size(pneumatic), mm	155×330 (350-6)

Table 2

Dimensions and Postures	Minimum	Maximum	Mean	SD
Age, years	18	37	22.6	5.6
Weight, kg	50	72	62.6	7.3
Stature, cm	164	179	172.1	4.7
Forearm hand length, cm	22.1	26.8	25.2	1.3
Upper arm length, cm	26.8	34	31.1	2.1
Hand length, cm	15.2	21	17.1	1.6
Shoulder horizontal abduction (α), degrees	22.6	31.5	27.1	3.2
Shoulder vertical abduction (β), degrees	16.5	24.2	20.7	2.6
Elbow extension (γ), degrees	134.1	169.3	150.1	10.9
Wrist extension (θ), degrees	160.5	174.8	169	5.5
Wrist deviation (ω), degrees	139.2	159.5	148.1	5.6

Table 2. Subject physical characteristics.

Dear Dr. Nguyen,

We appreciate editors very much for their constructive comments. We have revise our video according to the comments, and have uploaded the revised video to "Dropbox". We hope this revision can make our video more acceptable.

Thank you very much for your warm work. Looking forward to hearing from you.

Best regards.

Yours sincerely,

Rui Jiang

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Response to Editorial comments:

Thanks for your comments on the video. We have revised the video according to your comments:

Changes to be made by the Author(s) regarding the video:
06:39 - Please fade up the results tables instead of cutting in.
08:24 - Please fade out the figure to gray and fade up on the title.
09:25 - Please fade up on the text.

Response: Corrected.