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I. SUMMARY

On January 25, 1990, the National Institute for Occupational Safety and Health (NIOSH) conducted a health hazard evaluation of musculoskeletal disorders of the upper limbs and back at the Harley-Davidson Motorcycle Company in Milwaukee, Wisconsin. The objective of this evaluation was to identify job tasks in the flywheel milling area which may cause, aggravate, or precipitate musculoskeletal injuries, and to provide recommendations to decrease and prevent such injuries.

Approximately 253 motorcycle engines, and 170 motorcycle transmissions are fabricated and assembled each day at this plant. There are approximately 640 hourly workers (30% are female); 10 employees work in the flywheel milling area (all are male). Production is 24 hours per day with 2 to 3 workers working in the flywheel area per 8-hour shift. Occasionally, these workers may work 10- to 12-hour days to keep pace with production demands. The study included a walk-through survey of motorcycle engine fabrication and assembly, a review of OSHA 200 logs and medical compensation data, informal interviews with employees, and an in-depth ergonomic assessment of two jobs in the flywheel milling area. Data gathered indicated that potential musculoskeletal disorders could result at the elbow, shoulder, back, and hip during manual material handling of the flywheel during the milling process. Job risk factors which may cause disorders include manual transport of the flywheel between milling processes, placement of the flywheel in the milling machinery, and removal of this part when milling is complete. In addition, hand and wrist disorders may result from exposure to hazardous vibration frequencies from a hand-held power grinder used to remove metal burrs from milled flywheels and during manual tightening of this part onto the index milling machine.

Keywords: SIC 3751 (Motorcycle Manufacturing) Musculoskeletal Disorders, Manual Materials Handling, Cumulative Trauma Disorders, Metal Milling, Motorcycles, Ergonomics, Workstation Design, Engineering Controls.

II. INTRODUCTION

In January 1990, NIOSH received a request to perform a Health Hazard and Technical Assistance (HETA) Evaluation at Harley-Davidson Motorcycle, Inc., in Milwaukee, Wisconsin. The evaluation was requested by the Allied Industrial Workers, the International Machinist Unions, and Harley-Davidson Management. Both management and union officials were concerned about the number of musculoskeletal disorders reported by employees and the medical department which were associated with manual material handling and assembly tasks. Specifically, the company asked NIOSH researchers for assistance in evaluating musculoskeletal hazards associated with flywheel milling and requested recommendations to reduce such hazards.

On January 25, 1990, NIOSH researchers conducted a walk-through survey of the plant, performed an ergonomic evaluation of job risk factors for musculoskeletal disorders at the flywheel milling area, and reviewed employee medical record data.

III. WORK FORCE AND PHYSICAL PLANT AND PROCESS DESCRIPTION

Harley-Davidson Motorcycle, Inc., has three plants, one in Milwaukee, Wisconsin, another in Tomahawk, Wisconsin, and the third is in York, Pennsylvania. The plant in Milwaukee, Wisconsin, is responsible for the fabrication and assembly of Harley-Davidson motorcycle engines and transmissions. The plant in Tomahawk, Wisconsin, has 180 hourly employees and 20 salaried, and manufactures nonferrous parts such as windshields and saddle bags. The plant in York, Pennsylvania, is the largest of the three plants, with over 1,300 hourly workers and 300 salaried. This plant also does final assembly of the Harley-Davidson motorcycle.

The Milwaukee, Wisconsin plant, which is the subject of this evaluation, has approximately 640 hourly workers and 40 salaried workers. Thirty percent of the work force is female. The single-story plant was built in the early 1900's and has over 200,000 square feet for metal machinery, and 30,000 square feet for assembly. The plant manufactures and assembles motorcycle parts 24 hours a day, 7 days per week.

Flywheel Milling is located in Department #9. There are three flywheel milling "cells", each cell contains three to four milling machines, a drill press, and two to three work tables for removing medal burrs from post-milled flywheels and for quality control checks using calipers to match flywheel dimensions with company specifications. There are two flywheel sizes: the FL, which has a premilled weight of 18 to 19 pounds; and the XL, which has a premilled weight of 15 to 16 pounds. Approximately 3 pounds of metal is cut from each flywheel during the milling process. Each flywheel has a left (sprocket) side and a right (gear) side. When the flywheel is fully assembled, it consists of a sprocket and gear, crank pin, and two connecting rods. The premilled combined weight for the left and right flywheel is 37 pounds for the FL flywheel and 31 pounds for the XL. The weight of fully assembled post-milled flywheels and their components are: FL - 32.5 pounds and XL - 25.6 pounds.

Flywheel milling cells #1 and #2 are used to mill the left (cell #1) and right (cell #2) FL size flywheel. Flywheel milling cell #3 is used to mill both the left and right sides of the XL size flywheel. The crank pin and connecting rods are fabricated elsewhere in the plant; as is assembly of these components.

IV. DESIGN AND METHOD

A. Medical and Epidemiologic Assessment

This plant is faced with an array of circumstances that contribute to the problem of CTDs among the work force. These circumstances include a workforce made up of older workers, often with decades of experience on the same job, and the inherent ergonomic stresses present in an operation where machining of heavy components is involved. The situation is further complicated by the increase demand for the product in recent years, resulting in an inflexible demand for more units resulting in increased production pressures and more opportunity for work in excess of eight hour shifts. Within the construct of addressing process issues only, we have attempted to evaluate the ergonomic stresses specific to engineering and work practices recommendations to lower the levels so as to minimize further injury. However, it should be understood that proper evaluation of ergonomic stress should be viewed as an ongoing process, always with the aim of reducing stresses further by finding the proper balance of process speed, stress, and human factors.

We are unable to propose any epidemiological follow-up to determine the effectiveness of the interventions we propose, because of the large numbers of workers required to determine significance for such interventions. We encourage continued monitoring of the occurrence and cost of injuries, which is already being done as part of the insurance compensation program. The method, evaluation, results, and recommendations in this report may be used to develop ergonomic intervention strategies in other areas of the plant where you may have musculoskeletal problems. After you implement these recommendations, the risk of musculoskeletal injury should decrease.

B. Ergonomic Analysis

On January 25, 1990, NIOSH researchers conducted a walk-through survey of the motorcycle engine milling and assembly operations at Harley-Davidson Motorcycle, Inc. Following the walk-through survey, an in-depth ergonomic evaluation of the flywheel milling area was conducted.

The ergonomic evaluation consisted of: (1) discussions with flywheel milling employees regarding musculoskeletal hazards associated with their job, (2) videotaping the flywheel milling process, (3) biomechanical evaluation of musculoskeletal stress during manual handling of the flywheels, and (4) recording workstation dimensions and material process flow. Two flywheel milling cells (#2 and #3) were evaluated. Flywheel milling cell #1 was not evaluated, because the worker who normally operates this cell was not available; no replacement worker was used during this study.

Information gathered during the ergonomic evaluation was analyzed at the NIOSH research laboratories in Cincinnati, Ohio. Videotapes of the flywheel milling jobs were analyzed at regular speed for job cycle time, slow motion to determine musculoskeletal hazards of the upper limbs during manual material handling tasks, and stop-action to sequence job steps and perform biomechanical evaluations of working postures. All video analysis procedures were used to document potential musculoskeletal hazards in performing the job.

C. Work Documentation and Analysis

Time and motion study techniques were used for the first phase of job analysis.[1] Work methods analysis was used to determine the work content of the job. The flywheel milling job is described as a set of tasks, with each task consisting of a series of steps or elements,[1] that is, the fundamental movements or acts such as reaching, grasping, moving, positioning, use, etc., required to perform this job. Though Gilbreth suggested formal element definitions, which were called "Therbligs",[2] these elements were arbitrary in that one could increase or decrease detail as necessary. For example, "get" adequately describes the process of "reach-grasp-move," and "put" for "move-position-release." One identifies work elements by observing the job or by observing slow-motion videotapes of the job. "Tasks" are groups of elements that are usually performed in the same sequence to accomplish a common end. Examples of tasks for analysis of the flywheel milling job include "get flywheel from wheel cart," "position flywheel in milling machine," and "start milling machine."

The second phase of job analysis was to review the job for recognized occupational risk factors for CTDs. These CTD risk factors can be summarized as repetition, force, posture, contact stress, low temperature, and vibration.[3,4] In addition, biomechanical evaluation of forces which are exerted on the upper limbs, back, and lower limbs of the worker while performing the task can also be conducted. Such evaluations are aided by the use of formulas developed by NIOSH[5] and the University of Michigan Center For Ergonomics (2D Static Strength Software Program, version 4.0™). This two-phase approach for job analysis and quantification of forces which act upon the body during materials handling, forms the basis for proposed engineering and administrative control procedures aimed at reducing the risk for musculoskeletal stress and injury.

V. BACKGROUND

A. Cumulative Trauma Disorders of the Upper Limbs

Reports of chronic musculoskeletal disorders have been documented as far back as the year 1717 by the physician, Ramazini, who documented that certain occupations caused certain violent and irregular motions and unnatural postures of the body, which resulted in impairment and disease.[6] Several case reports over the years have cited certain occupational and nonoccupational risk factors which give rise to musculoskeletal injuries.[7,8,9,10] However, only recently have epidemiologic studies attempted to examine the association between job risk factors such as repetition, awkward postures, and force with excess musculoskeletal morbidity. Several cross-sectional and case-control retrospective studies of occupational CTDs have been employed.[11,12,13,14,15,16] The conclusions from these studies have drawn us closer to identifying risk factors with disease outcome. Work-related Cumulative Trauma Disorders (CTDs) of the upper limbs have been associated with job tasks that include (1) repetitive movements of the upper limbs, (2) forceful grasping or pinching of tools or other objects by the hands, (3) awkward positions of the hand, wrist, forearm, elbow, upper arm, shoulder, neck and head, (4) direct pressure over the skin and muscle tissue, and (5) use of vibrating hand-held tools. Because repetitive movements are required in many service and industrial occupations, new occupational groups at risk for developing cumulative trauma disorders continue to be identified.

One of the most commonly reported disorders of the upper limb is carpal tunnel syndrome (CTS). CTS is a median neuropathy of the wrist that can be caused, precipitated, or aggravated by repetitive, awkward postures and forceful motions.[15] Symptoms of carpal tunnel syndrome (CTS) include pain, numbness, and weakness of the hand, as a result of compression or irritation of the median nerve as it passes through the carpal tunnel in the wrist. Without intervention, CTS can lead to severe discomfort, impaired hand function, and disability. Workers who perform repetitive tasks are at risk of CTS and include automobile manufacturers and assemblers, electrical assemblers, metal fabricators, garment makers, food processors, grocery checkers, typists, musicians, housekeepers, and carpenters.[17,18,4]

The diagnosis is confirmed by physical examination and/or electrodiagnostic studies.[18] CTS can be managed with conservative measures, such as wrist immobilization and nonsteroidal anti-inflammatory medications.[17] However, these methods are not recommended as the main course of action, because symptoms are likely to recur when the patient resumes the precipitating tasks.[17] Recognition and evaluation of work-related risk factors which may cause CTS should be conducted in order to implement controls to reduce such risk factors. Engineering controls are the preferred method, with administrative controls such as work enlargement, rotation, etc., as an interim measure. For all patients with symptoms suggestive of CTS, an occupational history should be obtained that includes a description of tasks involving use of the hands. Failure to eliminate contributory job factors can result in recurrence or progression of symptoms, impaired use of the hand, and the need for surgical treatment. Redesign of tools, workstations, and job tasks can prevent occurrence of CTS among coworkers.[17] Surveillance of work-related CTS, including the use of health-care-provider reports, can aid in identifying high-risk workplaces, occupations, and industries and in directing appropriate preventive measure.[19]

B. Back Injuries

Eighty percent of all Americans will suffer low back pain sometime during their lifetime.[20,21,22,23] Over 30 million Americans currently experience low back pain;[24] 13 million of those cases have resulted in reduced ability to function.[25] Ten million cases of back impairment are in the employed U.S. population between the ages of 18 and 64.[25] Lost time from work has increased significantly over the past 30 years, while the incidence of low back pain has stayed the same.[26] Estimated total costs for low back pain is approximately 16 billion annually (compensable and noncompensable) in the United States.[24] The distribution of low back compensation costs is skewed: 25 percent of low back cases account for 95% of the costs.[27] Current estimates for low back compensation costs are approximately 6,807 dollars as the average or mean costs, and 390 dollars for the median.[27] The large difference between the mean and median shows that costs for low back pain are not evenly distributed where a few cases account for most of the costs.[27] The higher cost for the few cases were attributed to more hospitalization, surgery, litigation, psychologic impairment, and extended loss of time from work. Age, gender, and occupation are risk factors for the occurrence and severity of low back injuries. Old workers are more likely than younger workers to have severe back disorders.[28] More women than men are likely to have restricted-activity, bed disability, and work loss days.[29] Construction, Mining, Transportation, and Manufacturing are the occupations which show high rates of low back injuries.[30]

Occupational risk factors for low back injuries include manual handling tasks,[31] lifting,[32] twisting,[32] bending,[32] falling,[31] reaching,[33] excessive weights,[34,32,35] prolonged sitting,[36] and vibration.[37,38] Some nonoccupational risk factors for low back injury includes obesity,[39] genetic factors,[40] job satisfaction.[41,42]

Return to work following a back injury is dependent on the extent of injury as measured by the amount of time away from the job; the longer the worker was away from the job the less likely the worker would return to work.[43,44] Deterrents to returning to work include the worker such as psychological disability, management, no follow-up or encouragement, union, rigid work rules; the practitioner, too much treatment;[45] and attorneys, lump sum payment versus

rehabilitation [rehabilitation is 4.5 times higher, on average than lump sum payment].[46]
Control and prevention of low back pain can be accomplished through the evaluation of jobs and the identification of job risk factors. Bending, twisting, reaching, handling of excessive loads, prolonged sitting, and exposure to vibration are recognized risk factors for back injuries. Redesign of jobs can lead to the reduction of these risk factors and good job design initially will prevent back injuries. To reduce bending, twisting, and reaching by the worker, the work should be at the optimum work level - from waist to elbow height to reduce excessive bending and reaching; the workplace should be well laid out so as to reduce twisting; sit/stand workstations should be allowed where possible with good seat design so as to reduce prolonged sitting and standing; good package design such as hand holes for better coupling by the worker, package size so the worker can hold the load close to the body, and package weight so as not to exceed human capabilities.[5] Interim changes to reduce back injuries include job placement;[47] strength and fitness testing;[48,49,50] strength and fitness training (work hardening),[51,52] and work enrichment, enlargement, or rotation to reduce cumulative exposure. In addition to educating and training the worker, unions, and management about risk factors which cause back injury and pain, there appears to be no clear, single solution other than good initial job design. Multiple approaches such as job redesign, worker placement, and training may be the best methods for controlling back injuries and pain.[53]

Evaluation Criteria for Risk of Back Injury

The NIOSH Work Practices Guide for Manual Lifting,[5] was developed using medical, scientific, and engineering resources to develop quantitative recommendations regarding the safe load weight, size, location, and frequency of a lifting task. The recommendations assume that

1. the lift is smooth

2. the lift is two-handed and symmetric in the sagittal plane (directly in front of the body with no twisting during the lift)

3. the load is of moderate width, e.g., 30 inches or less

4. the lift is unrestricted

5. the load has good couplings (handles, shoes, floor surface)

6. the ambient environment is favorable

It is further assumed that other material handling activities such as holding, carrying, pushing, and pulling are minimal; that the individual performing the lifting activities is at rest when not lifting; and those involved in lifting are physically fit and accustomed to labor.

The formula used to analyze the various tasks is as follows:

Action Limit (AL) (lbs) = 90 (6/H) (1-.01|V-30) (.7+ 3/D) (1-F/Fmax);
(Maximum Permissible Limit (MPL) = 3 AL); where:

H = horizontal location forward of midpoint between ankles at origin of lift
V = vertical location at origin of lift
D = vertical travel distance between origin and destination of lift
F = average frequency of lift (lifts/minute)
Fmax = maximum frequency which can be sustained (table of values provided in Work Practices Guide)

Tasks analyzed in this manner are divided into three categories:

1. those above the Maximum Permissible Limit (MPL) which are considered unacceptable and which require engineering controls

2. those between the AL and MPL which are unacceptable without administrative or engineering controls

3. those below the AL which are believed to represent nominal risk to most industrial work forces.

The Work Practices Guide indicates that corrective action is needed for jobs which exceed the Action Limit. The incidence and severity rates of musculoskeletal injury have been found to increase in populations "exposed to lifting conditions" described by the Action Limit. It has been determined that over 75% of women and over 99% of men could (safely) lift loads described by the Action Limit.

C. <u>Segmental Vibration</u>

For more than 75 years, workers who operated vibrating tools on the job have reported symptoms resembling the signs and symptoms of primary Raynaud's disease.[54] These symptoms included episodic numbness and tingling of the fingers, episodic blanching of the fingers, with pain occurring in response to cold exposure and on return of circulation, and reduction in grip strength and finger dexterity. These signs and symptoms increased in number and severity as the exposure to vibration increased.[54]

It is estimated that 1.45 million workers use vibrating tools in the United States.[55] Worker populations which use vibrating tools have reported the prevalence of Hand-Arm Vibration Syndrome (HAVS) ranging from 6 to 100 percent. Risk factors for HAVS depends on many factors such as: the vibration energy produced by the tool, the length of time the tool is used each day, the cumulative number of hours, months, and years the worker has used the tool, and the ergonomics of tool use.

HAVS may take months or years to develop, and can be reversed in the early stages when recognized. However, advanced stages of HAVS are not reversible and lead to loss of effective hand function and necrosis of the fingers. Engineering controls, work practices, administrative procedures, medical supervision, worker training, ergonomic design of the tools and the task, and other procedures can be implemented to effectively reduce the risk of developing HAVS. While no specific Recommended Exposure Limits are provided in the NIOSH Criteria Document on Hand-Arm Vibration, it is recommended that engineering controls be the first level of protection through: (1) the elimination or reduction at the source (controlling acceleration of the tool), (2) reduction of transmission (the use of energy-damping materials between the tool and the worker's hands), and (3) process modification (ergonomic analysis and evaluation of work processes to determine vibration exposure sources and their elimination). Good work practices are also recommended, as are worker training and medical monitoring.[54]

VI. RESULTS

Ergonomic Evaluation and Analysis

1. Work Content

FL Flywheel Milling: The flywheel milling Cell #2 (FL-right side) operator performed a series of steps to mill the motorcycle flywheel to company standards. Seventy to 75 flywheels are milled per 8-hour shift in which 3 pounds of metal is cut from the right-side flywheel during this process. A description of the basic milling steps for the FL right side flywheel is shown in Table 1. The milling machines and work flow to complete the flywheel milling task is schematically shown in Figure 1.

XL Flywheel Milling: The flywheel milling Cell #3 (XL right and left side) operator performed a series of steps which were similar to the worker in Cell #2. Seventy-five to 80 flywheels are milled per 8-hour shift in which 3 pounds of metal is cut from the right and left sides of the flywheel during this process. The basic milling steps for the XL flywheels are described in Table 2. The milling machines and work flow to complete the flywheel milling task is schematically shown in Figure 2.

2. Cumulative Trauma

During the ergonomic evaluation of the flywheel milling jobs in flywheel milling work Cells #2 and #3, it was determined that these jobs were repetitive and required occasional awkward postures. There was considerable cumulative force involved in the form of flywheel lifting, movement, and processing during the work cycle. As such, in-depth analysis of the force risk factor was conducted to determine how much cumulative force, in the form of weight, each worker was exposed to each 8-hour workday. Tables 1 (FL flywheel milling) and 2 (XL flywheel milling) also show which work tasks had forceful motions that could be semi-quantified as a function of flywheel weight, when the flywheel was lifted, moved and positioned during the work process, which hand is involved in performing these motions, and the type of hand grip (pinch or power) used during these motions.

Cell #2: FL size flywheels have a premilled weight of approximately 19 pounds. After milling, these flywheels weigh approximately 16 pounds. Job analysis from videotapes taken during the NIOSH survey showed that the job cycle time to process flywheels ranged from 4 to 6 minutes, depending on the additional activities by the worker to prepare the machines for milling, material movement, milling time, and grinding (removal of metal burrs). It was determined that the job was comprised of 37 steps, in which the worker in flywheel milling Cell #2 performed approximately 45 definable job motions in which lifts, movements, and processing activities were done to complete one work cycle. Twenty-three of the 45 definable job motions could be semi-quantified by the amount of weight moved (average weight of the FL flywheel was 17.5 pounds) per job cycle. The amount of weight moved could be translated to terms of force (i.e., lifting and moving the flywheel from one location to another during the work cycle). Force, as it is used here can be expressed in terms of Newton's second law, where the time rate of change of momentum is proportional to the force which produces the change.[56]

Approximately 10 to 11 flywheels are milled per hour, with 70 to 75 milled per 8-hour shift. The estimated amount of accumulated weight handled by this worker is as follows: Average weight: 17.5 pounds (average 19 to 16 pounds), the number of times the flywheel was lifted, moved, and positioned (where force could be measured) per work cycle was 23; resulting in an accumulated number of pounds handled per work cycle at 402.5 pounds. If 10 flywheels are processed per hour with 7 hours of exposure (1 hour is for 10-minute work breaks, 2 in the morning and 1 in the afternoon, and 30 minutes for lunch), this results in an accumulated number of pounds handled per shift of **28,175** pounds (Table 3).

Additional factors which also increase force on the musculoskeletal system (but could not be measured or semi-quantified) should also be considered, such as how the flywheels are handled (pinch versus power grip), by which hand, and how often. For example, using the pinch grip (i.e., holding the part between the distal portions of the fingers and thumb - as in pulling a book from a bookshelf) versus the power grip (wrapping the fingers around the object - as in holding a hammer or baseball bat) can make a difference with regard to the amount of force required to do the job. The pinch grip is at a biomechanical disadvantage compared to the power grip, where pinch grips require more muscle strength which stresses the hand tendons and is more fatiguing than a power grip. During this evaluation, it was determined that of the 23 work elements which involved lifting or movement of the flywheel, 9 were done with the left hand, 11 with the right hand, and 3 were done with both hands. Of the 9 elements involving the left hand, 6 involved a power grip and 3 the pinch grip. Two of 11 work elements were done with the pinch grip of the right hand (Table 4).

The remaining 17 work elements performed to complete the work cycle of 45 elements were: removal of metal burrs (using a hand-held, in-line powered grinder) from the flywheel after milling in the CMC lathe and Machining Center; loosening and tightening the flywheels on the Shuttle's loading and unloading pallet (3510 T-10 Machining Center); and use of the air hose to blow off metal debris and oil. Removal of metal burrs was the most time consuming of these other activates (15%, or 33 seconds of 4:06 minutes of one work cycle), and appeared to be a risk factor for the development of hand and arm vibration related disorders.

Cell #3: XL size flywheels have a premilled weight of approximately 16 pounds. After milling, these flywheels weigh approximately 13 pounds. Job analysis from videotapes taken during the NIOSH survey showed that the job cycle time to process flywheels also ranged from 3 to 5 minutes. The change in cycle time depended on the additional activities by the worker to prepare the machines for milling, material movement, milling time, and grinding time (removal of metal burrs). It was determined that this job had 25 steps in which the worker in flywheel milling Cell #3 performed approximately 37 lifts, movements, and positioning activities to complete one work cycle. Seventeen of the 37 activities described above involved forces which could be measured in terms of flywheel weight (average weight of 14.5 pounds) for lifting, moving, and positioning, the flywheel from one location to another during the work cycle.

Approximately 11 to 12 flywheels are milled per hour, with 75 to 80 milled per 8-hour shift. The estimated amount of accumulated weight handled by this worker is as follows: Average weight: 14.5 pounds (average 16 to 13 pounds); the number of times handled per work cycle was: 17; resulting in an accumulated number of pounds handled per work cycle at 246.5 pounds. If 11 flywheels are processed per hour with 7 hours of exposure (1 hour is for two 10-minute work breaks in the morning and one 10-minute in the afternoon, with 30 minutes for lunch), this results in an accumulated number of pounds handled per shift of **18,980** pounds (Table 3).

As with Cell #2, the additional factors which add musculoskeletal strain from material handling includes how the flywheels are handled, by which hand, and how often. It was determined that of the 17 work elements which involved lifting or movement of the flywheel, 8 were done with the left hand, 9 with the right hand. Of the 8 elements involving the left hand, 1 involved a pinch grip, no pinch grips were observed with the right hand for flywheel lifting, movement, or positioning (Table 4). The remaining 20 work elements performed to complete the work cycle were: removal of metal burrs (using a hand-held, in-line powered grinder), from the flywheel after milling in the CMC lathe and Machining Center; loosening and tightening the flywheels on the Shuttle's loading and unloading pallet (3510 T-10 Machining Center); and use of the air hose to blow off metal debris and oil. Removal of metal burrs consisted of a larger percentage of the job cycle time (20 percent, or 39 seconds of 3:18 minutes for the work cycle), when compared with the percentage of time this activity was performed per work cycle in Cell #2. Metal grinding of the flywheels appeared to be a risk factor for the development of hand and arm vibration related disorders for this job.

3. Biomechanical Evaluation

Biomechanical evaluation of musculoskeletal forces on the upper limbs, back, and lower limbs for these jobs showed that certain job steps put these workers at risk for musculoskeletal disorders in which the allowable limits were exceeded for certain segments of the worker population. When the allowable limits are exceeded for certain elements of the job, then it is recommended that administrative or engineering controls be implemented. A comprehensive explanation of how the NIOSH allowable limits and maximum permissible limits were derived may be attained from the *Work Practices Guide for Manual Lifting*.[5] Strength predictions for each of the major articulations (joints) are explained in the textbook: *Occupational Biomechanics*.[57]

Cell #2 - Flywheel Milling: The biomechanical evaluation using the University of Michigan 2D Static Strength Prediction Program Version 4.0™, showed that there were some tasks that would exceed the biomechanical and static strength capabilities of this worker in relation to the demands of the job. Eighteen pounds of weight was used to simulate the weight of the flywheel; anthropometric data was adjusted to the dimensions of this worker who was in the upper 5 percentile (95th percentile) for the size and weight of the American male population. Posture and link angles were determined from stop action analysis of videotapes during the job cycle. Since one hand was used to perform the task, this was entered into the model.

Based on observation of the all the work elements in the job cycle, it was determined that one of the most biomechanically unsound postures was from placement of the flywheel in the Geared Head Drill Machine (see Table 1, step #5, and Figure 3). Analysis showed that the compressive forces on the back were 996 pounds and exceeded the NIOSH allowable limit (AL) of 770 pounds (Figure 4). In addition, the strength required to perform this job exceeded the NIOSH AL for the worker's elbow, shoulders, hip, and ankle, while performing this task (Figure 4).

When compressive forces exceed the NIOSH AL, administrative or engineering controls are recommended to decrease such forces and reduce the probability of musculoskeletal injury, especially the back. Reducing the reach distance between the worker and the flywheel by removing physical barriers is one of the easiest methods of control. Other control methods include reducing the weight of the object, use of two hands during lifting and transporting of loads, and automation.

Cell #3 - Xl Flywheel Milling: A biomechanical evaluation was also done for this workstation using the University of Michigan 2D Static Strength Prediction Program, V4.0™. Based on stop action analysis of the videotape for this job, it was determined that there were excessive strength requirements while the worker was removing the flywheel from the 3510 T-10 indexing machine and placing the flywheel on the work bench (see Table 1, step #11, Figure 5). Biomechanical analysis showed that the compressive forces for the low back did not exceed the AL of 770 pounds (Figure 6). However, the strength required to perform this job exceeded the AL for the elbow, shoulder, back (excluding low back), hip, and ankle (Figure 6). Administrative and engineering controls are recommended when such strength requirements are exceeded so as to reduce the chance of musculoskeletal disease and injury. Reducing the distance between the worker and where the worker has to place the flywheel will reduce the strength requirements for the job. This can be done by removing physical barriers in front of the worker from the floor to the working level. If physical barriers are not a problem, then the worker should be instructed to hold the flywheel closer to the body, using two hands when necessary, when putting the flywheel in place.

VII. DISCUSSION

This evaluation showed that there was excess musculoskeletal stress from flywheel handling. The musculoskeletal stress was from analysis of material handling during the work cycle and for biomechanical analysis of selected work elements during the work cycle. There was ample evidence to show that there was cumulative musculoskeletal stress during the work cycle and over the work shift. For example, the worker in Cell #2 (FL flywheel) lifted, moved, and positioned over 28 thousand pounds of metal flywheels over an 8-hour period, while the worker in Cell #3 (XL flywheel) lifted, moved, and positioned nearly 19 thousand pounds of metal flywheels during this same period. These estimates are conservative, since the total amount of weight handled by both workers is based only on what could be observed (lifts, movements, and positioning of flywheels on machines) and reliably counted (i.e., average flywheel weight - FL 17.5 pounds, XL 14.5 pounds). Static holding of these parts during grinding of metal burrs, tightening and loosening of bolts on the 3510 T-10 centering machine shuttle, and subtle movements of the flywheels also added to the cumulative musculoskeletal stress but could not be quantified. Even as a conservative estimate, the amount of weight handled on a daily basis puts these workers in a very exclusive group of individuals who have developed the strength and endurance to sustain such workloads.

The biomechanical analysis of job tasks showed that in some instances compressive back forces exceeded the NIOSH allowable limits (AL) and should be controlled through administrative or engineering controls. Administrative controls may be in the form of education and training the workers about methods of material handling. For example, if the worker in Cell #3 holds the flywheel closer to the body during lifting and transport, then the biomechanical forces and strength requirements are greatly reduced. Figure 7 shows how biomechanical forces and strength requirements can be reduced through proper materials handling. Often proper materials handling can not be done if physical barriers are between the worker and where the work is being done. In these instances barriers from the floor to the working level should be removed or relocated.

The biomechanical evaluation was conservative because of the restrictions inherent in the 2D Static Strength Model that was developed from the NIOSH Work Practices Guide. Such restrictions include (1) lifting a load directly in front of the body with no twisting. That is, the load should be lifted symmetrically (i.e., with two hands); (2) the lift should be done with equal loading of the muscle joints; (3) the lift should be smooth; and (4) the load should be unrestricted during the lift. As noted earlier in this report, such conditions did not exist for the workers evaluated by NIOSH researchers. Therefore, the biomechanical predictions for risk of injury to the various body links may be underestimated.

Segmental vibration of the hands and arms may also be a risk factor for musculoskeletal stress, notably hand-arm vibration syndrome. This syndrome may result from grinding metal burrs from the flywheels and the amount of time spent performing this task. In Cell #2, the FL flywheel worker spent approximately 15 percent of his cycle time performing grinding work, while the worker in Cell #3, the XL flywheel worker spent 20 percent of the job cycle grinding away metal burrs from flywheels. This means that the worker in Cell #2 is exposed to potentially hazardous vibration for approximately 63 minutes per day, while the worker in Cell #3 is exposed to potentially hazardous vibration for 84 minutes per day.

The work flow for Cell #2, the FL flywheel milling area, appeared reasonably well laid out although there was excess handling of the flywheels that resulted from the grinding operations that should be reduced. The process flow for Cell #3, the XL flywheel milling area, could be reduced by relocating the finished or post-milled flywheel cart next to the 3510 T-10 Machine Center and work table. This will reduce the added amount of musculoskeletal stress associated with manually transporting the flywheels approximately 45 to 50 feet to the back of the workstation.

Exact quantitative information does not exist in the published literature for the cause and effect of manual materials handling and risk of injury. However, the association between the amount and weight of materials handled and risk of injury suggests that even the strongest workers may not be able to sustain the workloads observed during the NIOSH evaluation. A prudent course of action would be to reduce the cumulative stress of materials handling by considering and implementing the recommendations which follow.

Conclusions

Several work tasks were evaluated for musculoskeletal disorders and injury for the FL Flywheel milling job in Cell #2, and the XL Flywheel milling job in Cell #3. Lifting and transporting flywheels during the milling process showed that the cumulative weight was in excess of 14 tons (28,175 pounds) for the worker in Cell #2, and in excess of 9 tons (18,980 pounds) for the worker in Cell #3. The estimates of weight handled are conservative because other work activities such as holding and positioning the flywheels with the hands, the type of hand grip used to handle the flywheels (pinch versus power grip), as well as segmental vibration exposure from the use of a hand-held power grinder were added risk factors. Tables 5 and 6 summarize the job steps shown in Tables 1 and 2, respectively, they note which of these job steps are risk factors for musculoskeletal disorders, and present recommendations for decreasing such risk factors.

VIII. RECOMMENDATIONS

Ergonomic Evaluation

A. Engineering Controls

1. The Harley-Davidson workers and management should continue to work closely in their "Vision" circles to determine how the initial weight of the flywheel can be reduced and thereby reduce the cumulative musculoskeletal stresses associated with the job over the work shift. *An excellent example of worker-company collaboration for ergonomic solutions through vision circles is noted in the development of the plastic wheel-cart used at the flywheel workstations.* A similar approach is encouraged for determining how the flywheel weight can be reduced by the supplier.

2. Reduce the initial weight of the flywheels by improving forging specifications and thereby reducing milling time and the amount of weight handled, especially for Cell #2, in which this worker handles over 14 tons of metal each day. Harley-Davidson engineers should consult with the supplier for improved forging specifications which should reduce costs per part, for shipping, milling, and hazardous waste removal (metal scrap and oil), and storage.

3. Reduce or eliminate exposure to the powered hand grinder used by workers to remove metal burrs from flywheels, especially for Cell #3, in which 20 percent of the work cycle consists of vibration exposure from tool use. Options to consider for reducing exposure include:

   a. Improved maintenance of drill bits and lathe blades, so that the edges are kept sharp and the flywheels can be milled true to minimize metal burrs. The maintenance program may include regular changing of drill and lathe blades with ones that are professionally sharpened.

   b. A pea-shot machine, where shot may be used only on areas where metal burrs exist.

   c. A tumbling machine to remove the burrs from the flywheel.

4. If the powered hand grinder is used to "touch-up" areas on the flywheel to remove metal burrs, it is recommended that the vibration spectrum of this tool be evaluated to determine if the vibration frequency is in the hazardous range (25 to 250 hz) to cause vibration-related disorders of the hands, including Raynolds syndrome. Check tools which do not have a hazardous frequency range through manufacturers who make such tools and have the performance specifications of the tools. Also, change grinding bits on tools frequently to reduce the manual force on the tools needed to remove the metal burrs.

5. A jig should be fabricated to secure the flywheel during the hand-grinding process. As viewed on the videotape, the workers free hand is used as a jig, or clamp, and results in unnecessary forces to hold the flywheel as well as

inefficient use of this hand. Consider fabricating a turntable-type jig with an attached quick clamp to secure the flywheel when using the grinder.

6. Organizational Layout and Process Control for Flywheel Milling.

   a. Flywheel milling cell #2: The flywheel is normally handled 45 times per job cycle from the time it is removed from the premilled wheel cart to the time it is placed back in the post-milled wheel cart. Each time the flywheel is handled, this results in musculoskeletal stress of the upper limbs and back. Consider flywheel handling carts and/or gravity conveyors between flywheel milling stations to reduce musculoskeletal stress.

   b. Flywheel milling cell #3: Reduce manual handling by using gravity conveyors and material handling carts.

   c. The post-milled flywheel cart for Cell #3 should be moved from the back of the cell to the front where the flywheel can be put into the cart rather then manually transporting it to the back of the workstation (see Figure 8 for recommended process flow and location of the finished or post-milled flywheel).

   d. The 3521 Cinturn unit appears to slow down the work flow. There also appears to be an abnormal amount of grinding of metal burrs from the flywheels when they come out of this machine. Check the lathe bits for sharpness and replace if needed. Consider mechanisms for speeding up the 3521 Cinturn unit processing time for the flywheels. This could be an area where engineers can work to improve forging specifications to reduce metal cut from the flywheel.

7. The metal pan that is built around the base of the indexing machine should be contoured, by rounding the corners to reduce contact trauma of the worker's upper legs and to reduce the reach distance for putting the flywheels on the indexing machines. Put an emergency stop switch on the machine to avoid pinch points during shuttle rotation.

8. Install floor matting around all three flywheel milling cells to reduce lower extremity fatigue of workers. The matting should be of a rubberized material that can be easily cleaned to reduce build up of metal debris.

9. Remove all physical barriers that may cause workers to overreach, such as limited toe and leg space where the worker has to reach over barriers to manually position flywheels for processing.

B. Work Practices

1. When manual handling of the flywheel is necessary, workers should use the "power grip" rather than the "pinch grip." The "pinch grip" requires handling of the flywheel by the fingertips and thumb, resulting in high musculoskeletal forces and fatigue. The power grip uses all of the fingers and the thenar eminences of the palm and results in less musculoskeletal stress and overall fatigue. Use of two hands is also recommended when handling parts to reduce asymmetric biomechanical loading of the limbs and back.

2. When wheel carts are brought into the flywheel milling cell, they should be brought in with the cart bumper facing away from the traffic area to avoid

contact with the worker's shins. To do this, the wheel carts could be color-coded or labeled on one side, so that they can be visually inspected and brought in the correct way by the forklift operator.

3. Operators should avoid overreaching while handling flywheels during milling. Overreaching may result in excess musculoskeletal stress and possibly injury, especially later in the work shift when the worker may become fatigued.

C. Administrative Controls

The physical demands of this job make it highly selective for strong workers who can tolerate such loads day-in and day-out. However, over the long run, even the strongest workers can wear out from repetitive tasks where 9 to 14 tons of metal are handled on a daily basis. It is recommended that the amount of handling be reduced through incorporation of the recommendations noted above. Worker rotation for this job is encouraged as an interim measure; this is especially encouraged when workers are on extended work shifts of 10 to 12 hours per day. It is also recommended that administrative controls should be used only until engineering controls are installed.

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TABLE 1

Cell #2: Basic Milling Steps for Processing the Fl-Right Side Flywheel

Table 1. Fl Flywheel: Description of Forceful Motions During Milling

Step No.	No. Reps./or Forceful motions	Description	Hand	Force Grip Type	Measured
1.	1x	Remove flywheel from 3507 Milling Machine & put on work table #1.	right	power	y
2.	1x	Get flywheel from wheel cart.	left	power	y
3.	1x	Put flywheel in 3507 milling machine, start milling Machine.	right	power	y
4.	1x	Get flywheel from 3692 Geared Head Drill Machine.	left	power	y
5.	1x	Put flywheel on work table #2.	right	power	y
6.	1x	Get flywheel from work table #1 and position in 3692 Geared Head Drill Machine, start drill machine.	left	power	y
7.	1x	Get flywheel from 3523 Cinturn Milling Machine and put on work table #3.	left	pinch	y
8.	1x	Get flywheel from Work Table #2 and put in 3523 Cinturn Milling Machine, start milling machine.	right	power	y

(continued)

TABLE 1 (continued)

Step No.	No. Reps./or Forceful motions	Description	Hand	Force Grip Type	Measured
9.	1x	Work Table #3: Hold flywheel (hand used as clamp to hold fly-wheel in place).	left	pinch	
10.	1x	Work Table #3: Use power grinder to remove metal burrs.	right	power	
11.	1x	Work Table #3: Quality control check - hold flywheel with hand to check.	left	pinch	
12.	1x	Work Table #3: Quality control check - Use calipers to check part.	right	pinch	
13.	1x	Position flywheel on work table #3 following quality control check.	right	power	y
14.	4x	Loosen 4 bolts on fly-wheel clamp from 3510 T-10 Machining Center.	right	power	
15.	1x	Move flywheel from 3510 Machining Center to Work Table #3.	both	pinch	y
16.	1x	Work table #3: Hold flywheel for grinding of metal burrs.	left	pinch	
17.	1x	Use power grinder to remove metal burrs.	right	power	
18.	1x	Move flywheel to 3510 T-10 Machining Center.	left	power	y

(continued)

TABLE 1 (continued)

Step No.	No. Reps./or Forceful motions	Description	Hand	Force Grip Type	Measured
19.	1x	Position flywheel on 3510 T-10 Machining Center. Note: Machining Center can hold up to 8 flywheels at one time.	right	power	y
20.	1x	Remove flywheel from 3510 T-10 Machining Center and put on Work Table #3.	both	pinch	y
21.	1x	Work Table #3: Hold flywheel for grinding of metal burrs.	left	pinch	
22.	1x	Work Table #3: Use power grinder to remove metal burrs.	right	power	
23.	1x	Move flywheel from work table #3 to 3510 T-10 Machining Center.	left	power	y
24.	1x	Position another flywheel on 3510 T-10 Machining Center.	right	power	y
25.	4x	Tighten 4 bolts with tool on 3510 T-10 Machining Center.	right	power	
26.	1x	Move another flywheel from Work Table #3 to 3510 T-10 Machining Center.	right	pinch	y
27.	1x	Position flywheel on 3510 T-10 Machining Center.	both	pinch	y
28.	2x	Tighten 2 bolts on jig of 3510 T-10 Machining Center.	left	power	

(continued)

TABLE 1 (continued)

Step No.	No. Reps./or Forceful motions	Description	Hand	Force Grip Type	Measured
29.	2x	Tighten 2 bolts on jig 3510 T-10 Machining Center, start machining center.	right	power	
30.	1x	Move flywheel from 3619 Grinder Machine and put on Work Table #5.	left	pinch	y
31.	1x	Get flywheel from Work Table #4 and move to 3619 Grinder Machine.	left	power	y
32.	1x	Position flywheel in 3619 Grinder Machine machine.	right	power	y
33.	1x	Work Table #5: Quality Control check of flywheel (hold in position).	left	pinch	
34.	1x	Work Table #5: Quality Control check of flywheel (measure with calipers).	right	pinch	
35.	1x	Move flywheel from Work Table #5 to 3675 Dodson Milling Machine.	right	pinch	y
36.	1x	Position flywheel in 3675 Dodson Milling Machine.	right	power	y
37.	1x	Get flywheel from 3675 Dodson Milling Machine and position in wheel cart.	left	pinch	y
Repeat work cycle.					

TABLE 2

Cell #3: Basic Milling Steps for Processing the XL (Both Sides) Flywheel

Table 2. Xl Flywheel: Description of Forceful Motions During Milling

Step No.	No. Reps./or Forceful motions	Description	Hand	Force Grip Type	Measured
1.	1x	Remove flywheel from 2819 Sheldon Lathe and set on Sheldon Lathe tray.	right	power	y
2.	1x	Get flywheel from flywheel cart.	left	pinch	y
3.	1x	Position flywheel in 2819 Sheldon Lathe, start lathe.	right	power	y
4.	1x	Remove flywheel from 3539 Special Drill Unit and position on work table #1.	right	power	y
4.	1x	Move flywheel to 3539 Special Drill Unit.	right	power	y
5.	1x	Position flywheel in 3539 Special Drill Unit, start drill unit.	left	power	y
6.	1x	Move flywheel from work table #1 to work table #2.	left	pinch	y
7.	1x	Remove flywheel from 3521 Cinturn and position on work table #1.	right	power	y
7.	1x	Move flywheel from work table #2 to 3521 Cinturn.	left	power	y

(continued)

TABLE 2 (continued)

Step No.	No. Reps./or Forceful motions	Description	Hand	Force Grip Type	Measured
8.	1x	Position flywheel in 3521 Cinturn, start machine.	right	power	y
10.	1x	Hold flywheel for grinding (hand used as clamp to hold flywheel in place).	left	pinch	
11.	1x	Use power grinder to remove metal burrs from flywheel.	right	power	
12.	1x	Move flywheel from work table #1 to 3510 T-10 Machining Center.	right	power	y
13.	2x	Tighten 2 bolts on 3510 T-10 Machining Center.	right	power	
14.	2x	Loosen 2 bolts on 3510 T-10 Machining Center.	right	power	
15.	1x	Remove, and place flywheel from 3510 Machining Center on work table #3.	left	power	y
16.	2x	Loosen 2 bolts on 3510 T-10 Machining Center.	right	power	
17.	1x	Remove, move and place flywheel from 3510 Machining Center on work table #3.	left	power	y
18.	4x	Loosen 4 bolts on 3510 T-10 Machining Center	right	power	

(continued)

TABLE 2 (continued)

Step No.	No. Reps./or Forceful motions	Description	Hand	Force Grip Type	Measured
19.	1x	Remove, move and place flywheel from 3510 Machining Center on other corner of this machine to do reverse side milling.	right	power	y
20.	2x	Tighten 2 bolts on 3510 T-10 Machining Center.	right	power	
21.	1x	Remove, and place flywheel from 3510 Machining Center on other corner of this machine to do reverse side milling.	left	power	y
22.	2x	Tighten 2 bolts on 3510 T-10 Machining Center.	right	power	
23.	2x	Work table #3 Hold flywheel with hand for grinding.	left	pinch	
24.	2x	Use power grinder to remove metal burrs from flywheel.	right	power	
25.	2x	Move flywheels from table #3 to wheel cart (transport of fly-wheels with both hands); place in wheel cart.	right left	power power	y y

Repeat work cycle.

TABLE 3

Summary of Activities Performed for Flywheel Milling in Cells #2 and #3.

Description	FL Flywheel	XL Flywheel
Flywheel Weight (lbs)		
Initial weight	19	16
Final weight	16	13
Average	17.5	14.5
Cycle time (range in minutes)	4-6	3-5
Timed work cycle (minutes)	4.06	3.18
No. Flywheels/hour	10-11	11-12
No. Flywheels/8-hour day	70-75	75-80
No. Job Steps	37	25
No. Job Motions*	45	37
No. Motions with Force**	23	17
No. pounds moved/work cycle[1]	402.5	246.5
No. pounds moved/8-hour shift[2]	28,175	18,980

* No. Job Motions: No. of motions where hands were used for flywheel work.

** No. Motions with Force: No. motions where hands were used for flywheel lifting, movement, and placement.

1. No. pounds moved/work cycle = Average weight of flywheel X No. of motions with force.

2. No. of pounds moved/8-hour shift = Average weight of flywheel X Average No. of flywheels per hour X 7 hours of exposure.

TABLE 4

Analysis of Work Performed by Hand and Type of Grip Used to Perform Work

# Job Steps	#Job Elements	# Motions with Force	Hand Used	#Times Hands Used	Grip Type # Power	Pinch
FL 37	45	23	right	19	15	4
			left	15	7	8
			both	3	0	3
			Total	27	22	15
XL 25	37	17	right	17	17	0
			left	10	6	4
			both	0	0	0
			Total	27	23	4
FL - # Motions with Force.		23	right	11	9	2
			left	9	6	3
			both	3	0	3
			Total	23	15	8
XL - # Motions with Force.		17	right	9	9	0
			left	8	7	1
			both	0	0	0
			Total	17	16	1

TABLE 5

Reference Step #'s from Table 1.	Problem	Recommendation
2.	Reaching and pulling fly-wheel from cart; pinch grip in handling part; excessive forces in materials handling, especially for break away forces when flywheels are jammed in cart.	Stack parts in cart by using pre-formed plastic separators; use to 2 hands to handle flywheel; reduce reach for flywheel by orienting parts toward worker and moving cart closer to 3507 milling machine.
1,3	Excessive asymmetric loading of right upper limb to position flywheel into 3507 milling machine. Loads lifted asymmetrically can import complex and potentially hazardous stresses to the lumbar spine.	Reduce reach distance by standing closer to machine and use two hands to position flywheel.
4,6.	Excessive biomechanical loading of upper limbs and back when placing flywheel in 3692 Geared Head Drill machine.	Minimize reach requirements for placing flywheel in the drill machine by removing obstacles between machine and the worker. Example: Relocate palm buttons closer to drill head.
7,15, 20,26, 30,37, 35.	Pinch grip, while lifting & moving flywheel. Pinch grip requires more muscle strength which stresses the hand tendons and is more fatiguing than the power grip.	Use a power grip whenever possible because of superior biomechanical leverage; use material handling devices such as gravity conveyors and push wheel carts, where possible.
9,16, 21.	Static holding work. Left hand used as jig or clamp while other hand is used to operate grinder.	Fabricate a jig or clamp to hold the flywheel. The jig should be easily rotated, such as on ball barring, to easily access all areas of flywheel for metal grinding.

(continued)

TABLE 5 (continued)

Reference Step #'s from Table 1.	Problem	Recommendation
10,17, 22.	Potential hand-arm vibration hazard from use of hand held power grinder to remove metal burrs from flywheel.	Reduce exposure by reducing use of vibrating tool. This can be done by substituting the grinding tool with a tumbling machine, or using a pea shot machine. Interim options include regular changing of grinding bits to reduce the amount of manual force needed to remove burrs, better milling from the lathes which reduces the amount of burrs to be removed, and use of vibration dampening devices to reduce vibration transmitted to the hands. See additional recommendations in section IX of this report.
19,24, 27.	Reaching to position flywheel on 3502 cinturn milling machine to do milling of flywheel.	Contour metal catch pan at the bottom of the indexing machine to match turning radius of indexing machine, this will reduce manual reaching while positioning the flywheel. Attach a safety cord (dead man switch) to avoid pinch points.
32.	Excessive biomechanical loading from positioning of flywheel in 3619 grinder. The back and upper limbs are at risk.	Reduce loading by minimizing reach distance to grinder fixture by relocating part tray on front of grinder a side location.
37.	Placement of finished flywheel (post-milled) in cart.	Stack parts in cart by using preformed plastic separators. This will allow for easier stacking and later unstacking. It will also protect the flywheel metal finish.

(See Table #1 for Job Steps referred to in this table.)

TABLE 6

Reference Step #'s from Table 2	Problem	Recommendation
2.	Reaching and pulling flywheel from wheel cart; pinch grip in handling part; excessive forces in materials handling; especially for break away forces when flywheels are jammed in cart.	Stack parts in cart by using preformed plastic separators; use 2 hands to handle flywheel; reduce reach and flywheel handling by orienting parts toward worker and moving cart closer to milling machine.
5.	Positioning flywheel in 3539 Special Drill unit with one hand causes excess asymmetric biomechanical mechanical loading on the shoulder.	Handle part with both hands when positioning flywheel in drill unit; minimize reach distances by standing as close to the drill unit as possible. Relocate obstacles to stand closer to the drill unit.
6.	Awkward handling of flywheel may cause excessive biomechanical stress on upper limbs, especially to the hands and wrists.	Reduce biomechanical stress on upper limbs by handling part with two hands, use wheel-carts or conveyors (where possible) to move flywheels from one machine to another; use power grip (handle flywheel by its spindle and balance load while handling.
11,24.	Use of powered hand grinder to remove metal burrs from flywheel may cause hand and arm vibration related disorders.	Reduce exposure by reducing use of tool. Better milling from sharper lathe blades should reduce the time and amount of grinding of metal burrs. A tumbling machine, or pea shot should also be considered for removal of metal burrs.

(continued)

TABLE 6 (continued)

Reference Step #'s from Table 2	Problem	Recommendation
15,17, 19,21.	Excess biomechanical loading from extended reach in positioning flywheel on 3510 T-10 Cintern indexing machine.	Contour metal catch pan at the bottom of the indexing machine to match turning radius of indexing machine. This will reduce manual reach while positioning flywheel on the indexing machine.
15,17.	Excessive strength requirements for upper limbs and lower back from placing flywheel on work table #3 from 3510 T-10 machine.	Reduce reach distance by positioning work table closer to indexing machine, or keeping flywheel close to body when positioning on work table.
25.	Unnecessary biomechanical loading of upper limbs from manually transporting flywheels from work table #3 to flywheel (post-milled) wheel cart.	Relocate wheel cart next to 3510 T-10 indexing machine to reduce handling and improve work efficiency.
25.	Place finished flywheel (post-milled) in cart.	Stack parts in cart by using preformed plastic separators for easier stacking and later unstacking, and to protect the flywheel metal finish.

(See Table #2 for Job Steps referred to in this table).

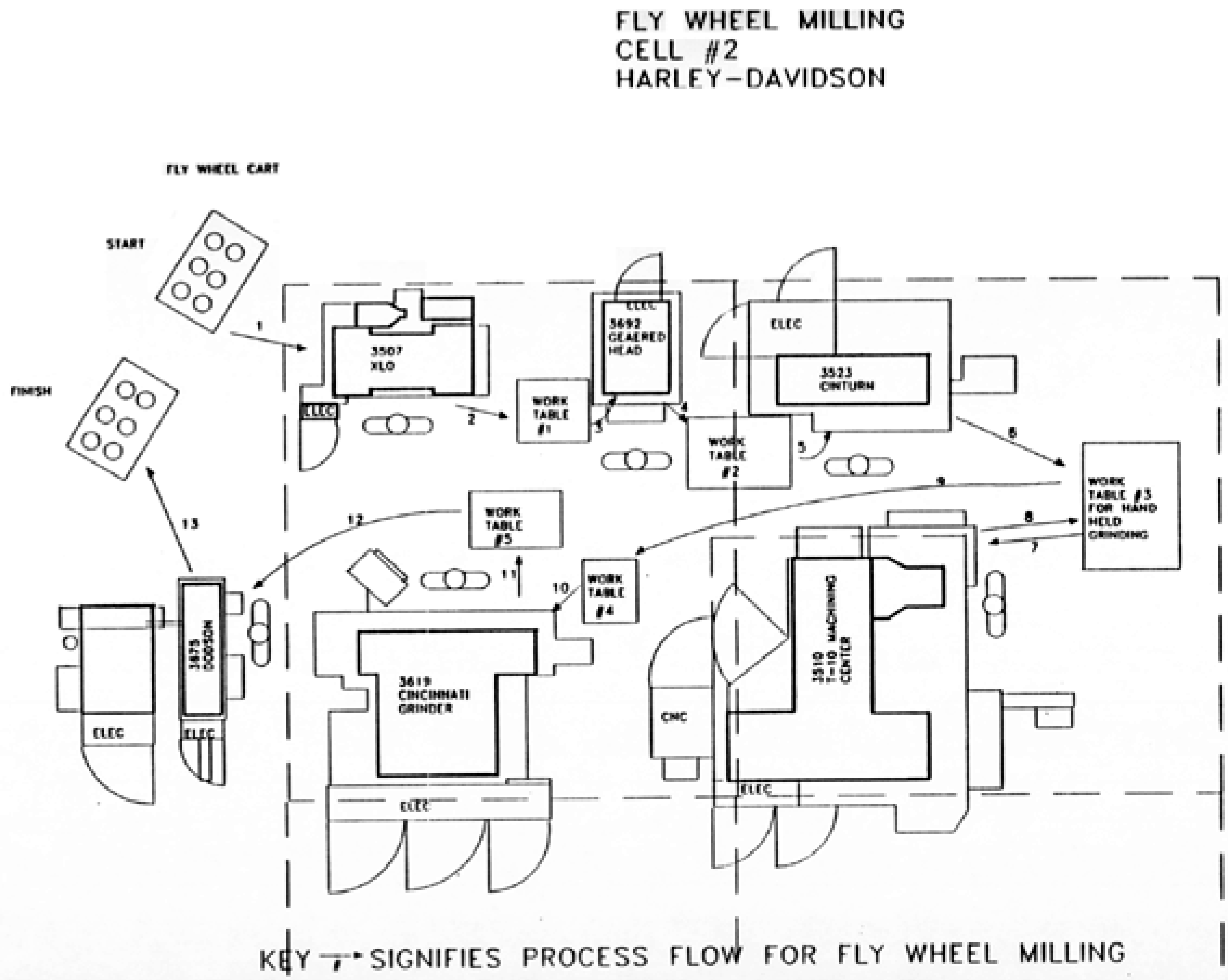


Figure 1. Plan View of FL Flywheel Milling Machines and Milling Process.

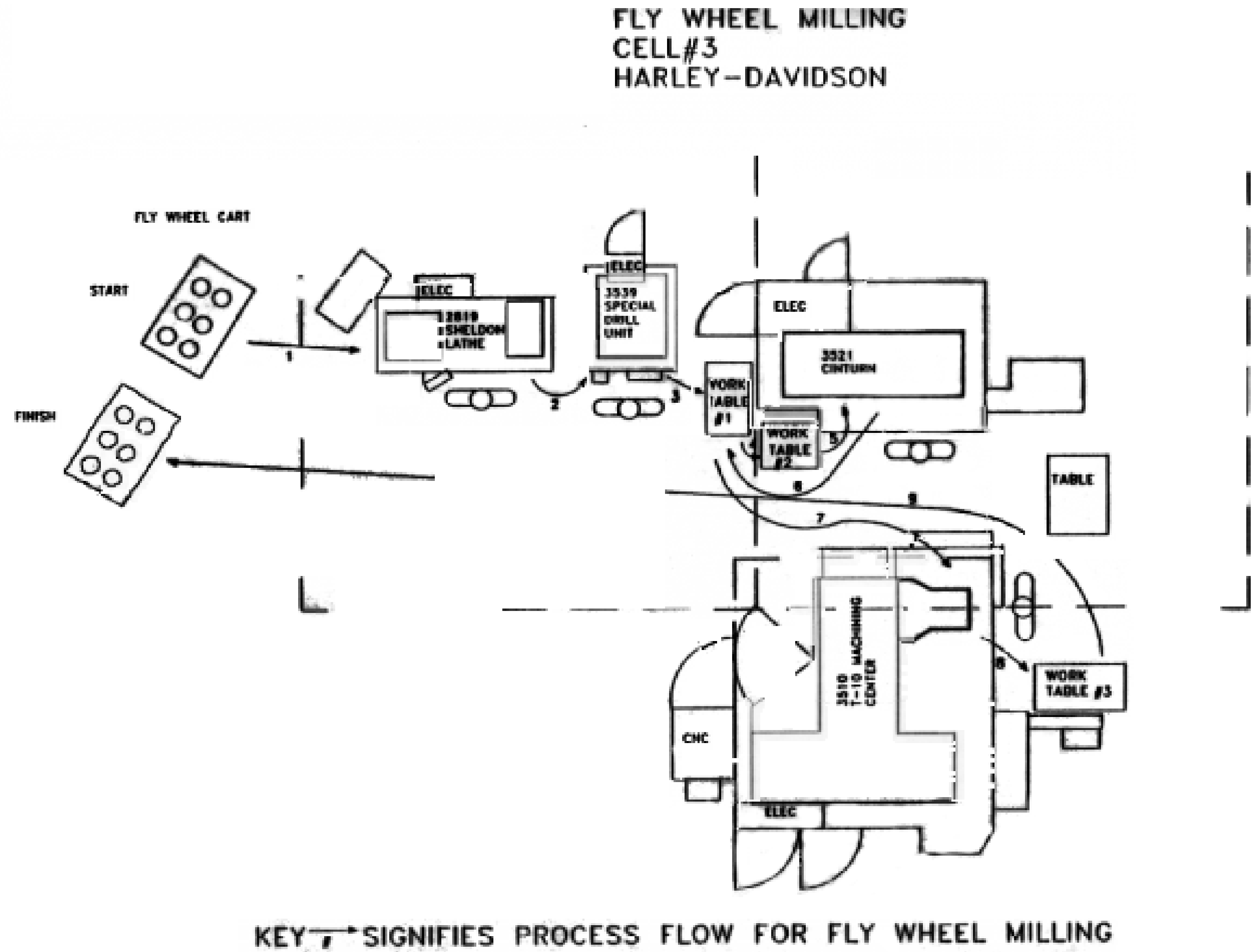


Figure 2. Plan View of XL Flywheel Milling Machines and Milling Process.

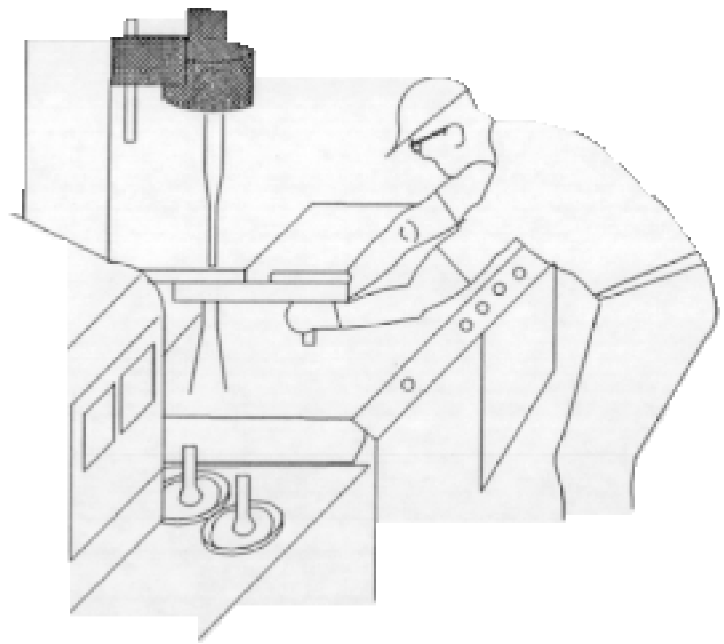
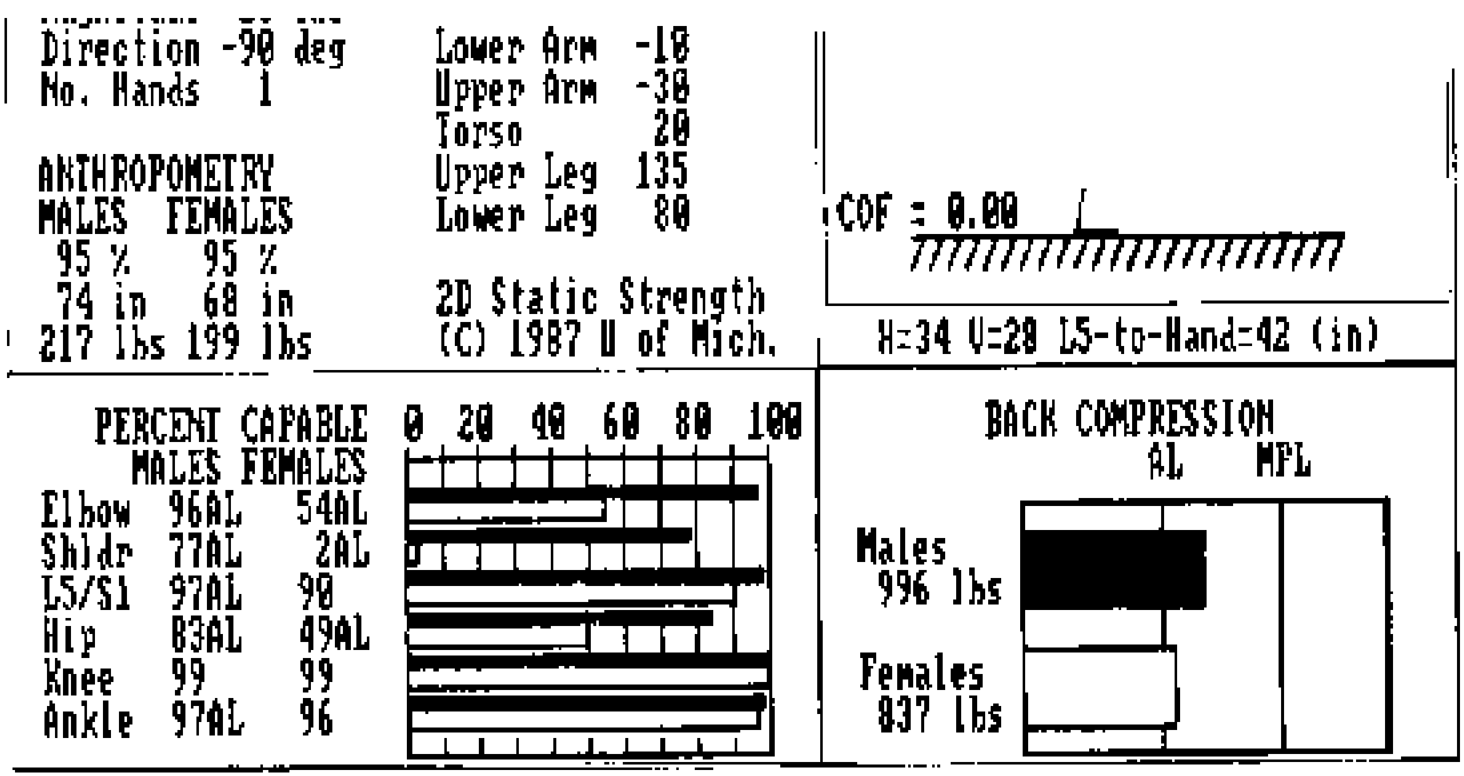


Figure 3. Worker Positioning FL Flywheel in Geared Head Drill Machin



BACK COMPRESSION

```
              500      1000      1500      2000  LBS
         |---------|----|----|-------|-|---------|----------|
Males    |MMMMMMMMMMMMMMMMMMMMM                     996 lbs |
Females  |FFFFFFFFFFFFFFFF                          837 lbs |
         |---------|----|----|-------|-|---------|----------|
              500      1000      1500      2000  LBS
                    AL          MPL
                    770         1430
```

Figure 4. Analysis of Force Parameters, Anthropometry Data, Back Compressive Forces, Strength Requirements, and Postural Graphic of Worker Positioning FL Flywheel in Geared Head Drill Machine.

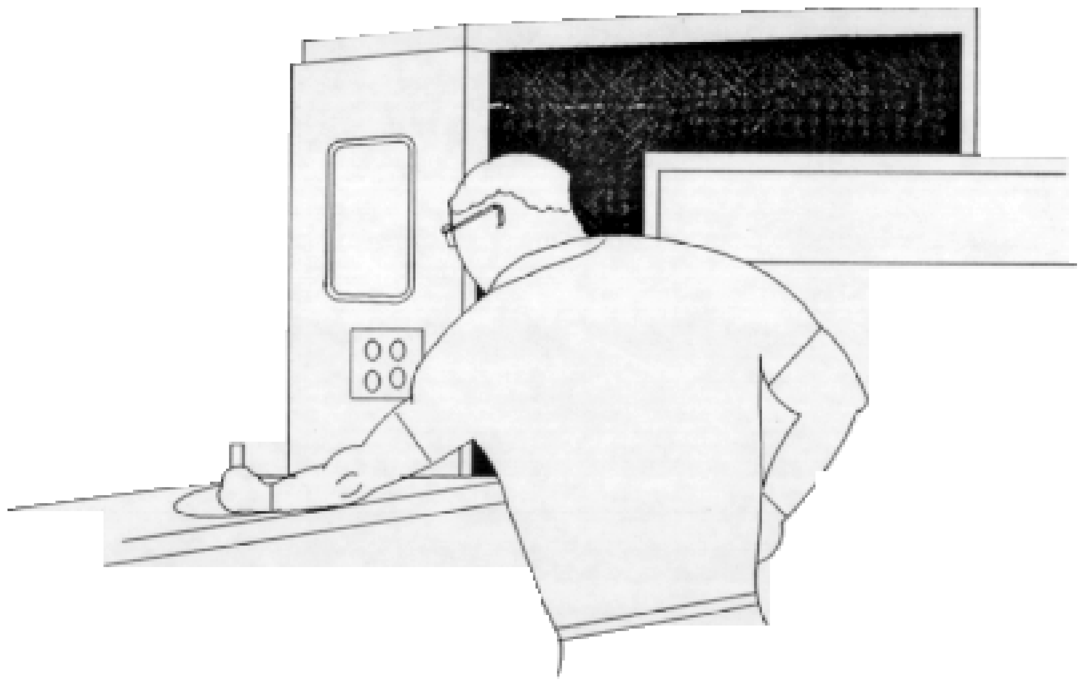
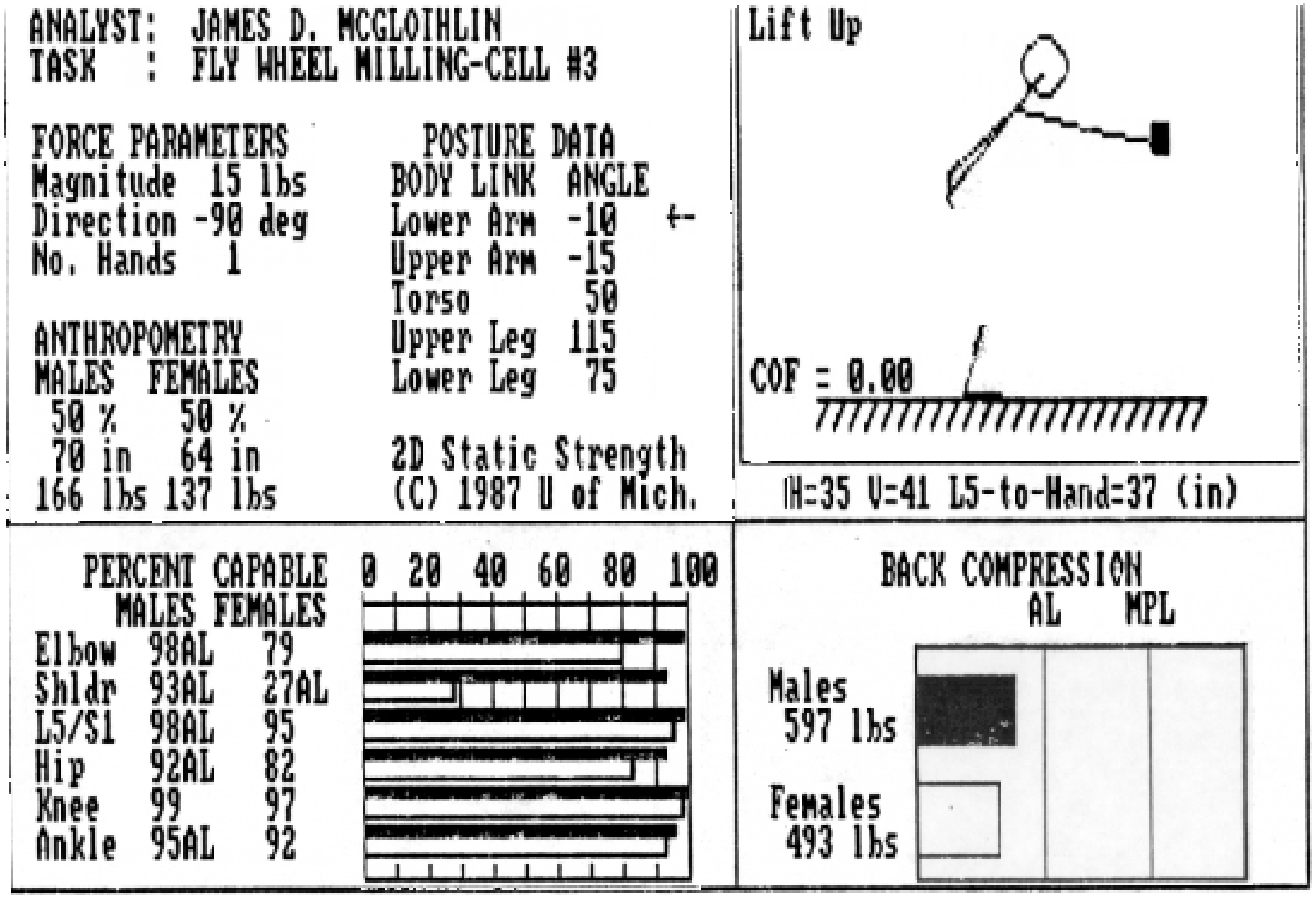


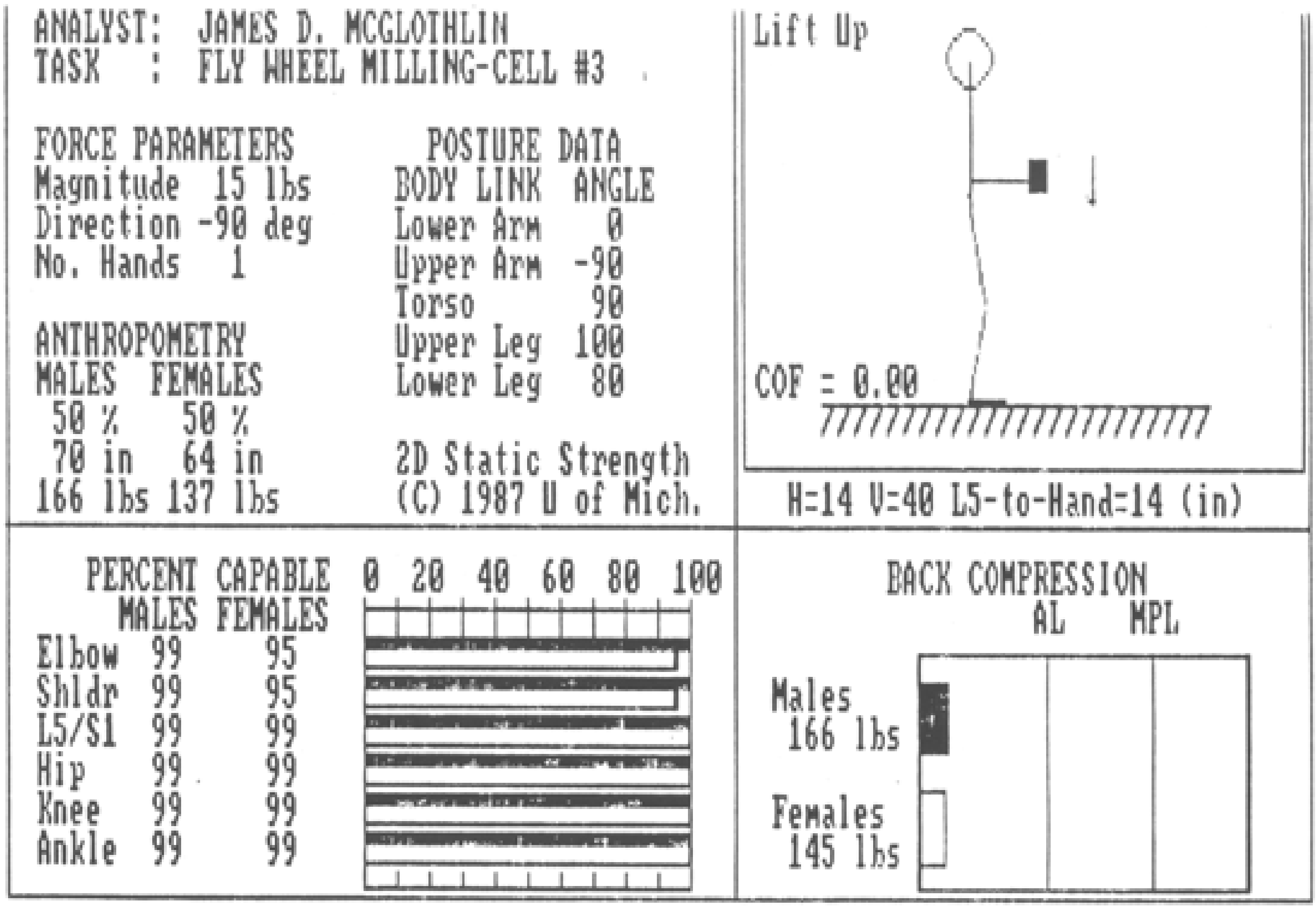
Figure 5   Worker Po tion ng XL F ywhee on Work Table




```
                        BACK COMPRESSION

                     500      1000      1500      2000   LBS
          |---------|----|----|-------|-|---------|----------|
Males     |MMMMMMMMMMMM                             597 lbs  |
Females   |FFFFFFFFFF                               493 lbs  |
          |---------|----|----|-------|-|---------|----------|
                     500      1000      1500      2000   LBS
                          AL         MPL
                          770        1430
```

Figure 6. Analysis of Force Parameters, Anthropometry Data, Back Compressive Forces, Strength Requirements, and Postural Graphic of Worker Positioning Flywheel on Work Table.




```
                    BACK COMPRESSION

                500       1000      1500      2000  LBS
          |---------|----|----|-------|-|---------|----------|
Males     |MMMM                                     166 lbs |
Females   |FFF                                      145 lbs |
          |---------|----|----|-------|-|---------|----------|
                500       1000      1500      2000  LBS
                         AL         MPL
                        770         1430
```

Figure 7. Analysis of Force Parameters, Anthropometry Data, Back Compressive Forces, Strength Requirements, and Modified Postural Graphic of Worker Positioning Flywheel on Work Table Without Extended Reach.

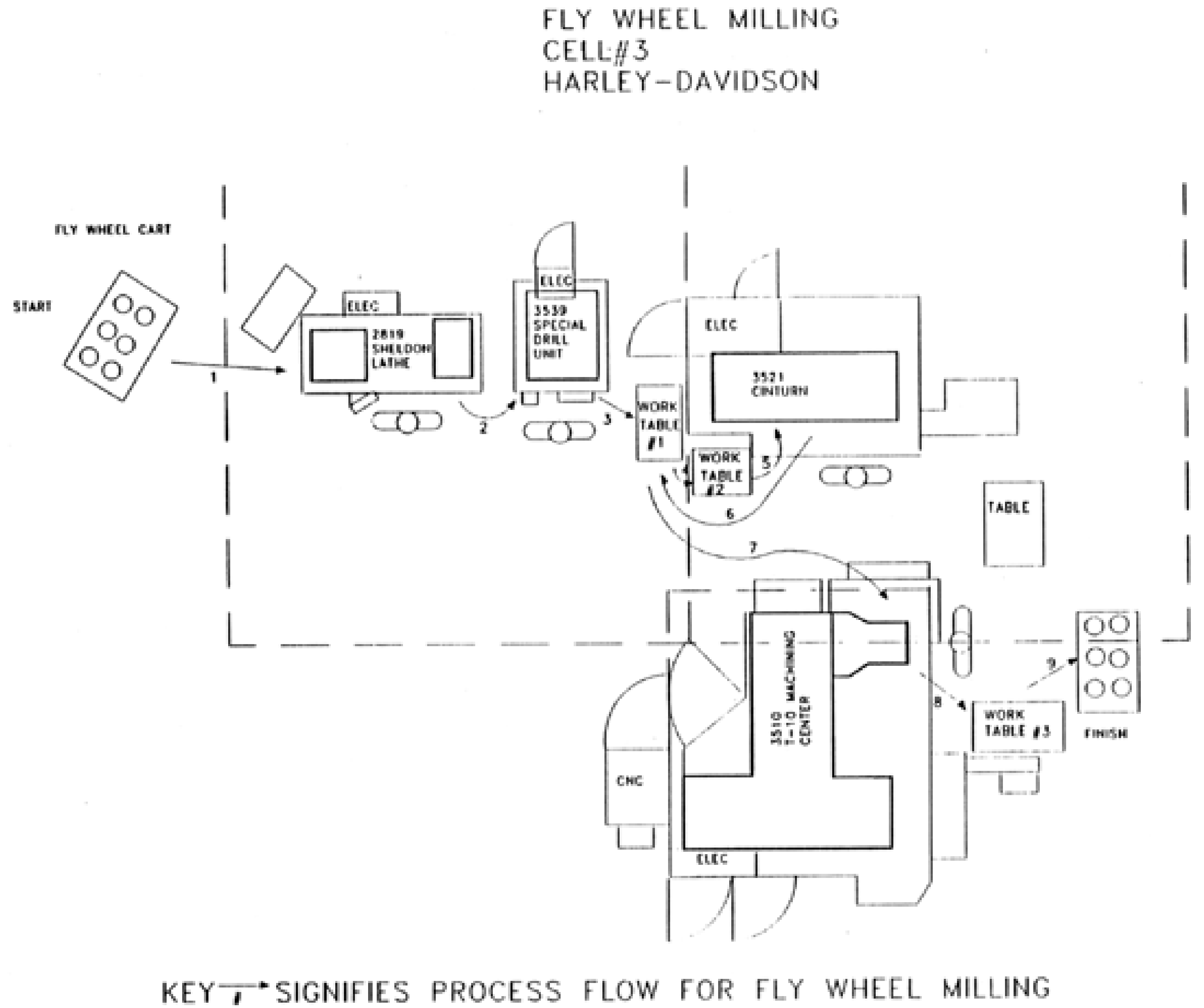


Figure 8. Recommended Physical Layout for Milling and Processing XL Flywheels.