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I. SUMMARY

Researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted initial[1] and follow-up health hazard evaluations of musculoskeletal disorders of the upper limbs and back at Harley-Davidson Incorporated, a motorcycle manufacturing company, over a 44 month period (January 1990 - August 1993). The objective of this evaluation was to identify job tasks in the flywheel milling department which may cause musculoskeletal injuries, and to provide recommendations to decrease and prevent such injuries.

NIOSH researchers reviewed the Bureau of Labor Statistics Log and Summary of Occupational Injuries and Illnesses (otherwise known as the OSHA 200 logs) and conducted an ergonomic evaluation of 4 jobs (2 flywheel milling, 1 truing flywheels, 1 flywheel balancing) in this department. Data gathered on the initial site visit in the flywheel milling area showed that repeated manual transport, placement, and removal of the flywheels between milling processes resulted in over 28,000 lbs. handled per 8-hour shift. In addition, repeated use of a hand-held power grinder to remove metal burrs from milled flywheels proved to be inefficient and potentially hazardous. Analysis of data from the flywheel truing job showed impact forces from the 5-lb. brass hammer repeatedly striking the flywheel ranged from 25,000 to 92,000 lbs. Analysis of the flywheel truing and balancing jobs showed potential risk for back injury, according to the revised NIOSH formula for manual lifting. Based on the initial evaluation, NIOSH provided recommendations to reduce these risk factors. The recommendations focused on reducing manual material handling, and increasing productivity and product quality. The company responded by forming an ergonomic committee consisting of management and labor to solve problem jobs in this department.

The committee focused on designing, redesigning, or eliminating jobs where musculoskeletal hazards were identified. Lighter flywheel castings from improved die-cast specifications, product flow, and better milling machines resulted in a reduction of flywheel handling to 17,500 lbs per 8-hour day. A customized 40-ton press eliminated the need for brass hammers, and an overhead lift eliminated manual handling of the assembled flywheel unit. During this five year period, 1989-1993, there was a reduction in the rate of cases of work-related musculoskeletal disorders involving lost or restricted workdays from 27.6 per 100 workers in 1989 to 12.5 per 100 workers in 1993. There was also a decrease in the severity rate of musculoskeletal disorders from 610 lost or restricted workdays per 100 workers in 1989 to 190 days in 1993. The process of evaluation and redesign of the flywheel department to reduce musculoskeletal disorders is presented as a model for reducing and preventing such disorders in this industry.

On the basis of the information collected during this evaluation, NIOSH researchers determined that musculoskeletal hazards were significantly reduced following the development of an ergonomic program to improve the workstation design. However, potential for overexertion injuries to the back still exists in the flywheel assembly and truing jobs due to manual handling of flywheel assemblies. Recommendations for further reducing and preventing such hazards are presented in Section VI of this report.

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

II. BACKGROUND

In the winter of 1990, NIOSH received a joint labor/management request from the Milwaukee facility of Harley-Davidson to evaluate musculoskeletal disorders of the upper limbs and back. Particular concern was expressed about the flywheel milling areas. The trigger for the NIOSH request was an increase in workers compensation costs due to an increased number of injuries. This increase occurred because of a number of factors including improved record keeping, increased awareness of work-related musculoskeletal injuries, an economic recovery resulting in the hiring of new workers, and other factors.

Based in part on the initial NIOSH report,[1] several ergonomic interventions were developed and implemented by the company. NIOSH then received a second joint labor/management request to evaluate these interventions. NIOSH representatives conducted a follow-up evaluation in May 1992, August 1992, October 1992, and August 1993. These visits generated information on the rates of reported musculoskeletal disorders and evaluated the ergonomic interventions that had already occurred and those that were ongoing.

A. Work-Related Musculoskeletal Disorders

Several case reports over the years have cited certain occupational and nonoccupational risk factors which give rise to musculoskeletal injuries.[2,3,4,5] However, only recently have epidemiologic studies (cross-sectional and case-control retrospective studies) been conducted that have examined the association between job risk factors (such as repetition, awkward postures, and force) and excess musculoskeletal morbidity.[6,7,8,9,10,11] These studies have identified relationships between these risk factors and the development of musculoskeletal disorders.

Upper Limbs

Work-related musculoskeletal disorders (WRMDs) 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, occupational groups at risk for developing WRMDs of the upper limb continue to be identified.

Evaluation of work-related risk factors which may cause upper limb WRMDs should be conducted in order to implement controls to reduce these risk factors. Engineering controls are the preferred method; however, administrative controls such as work enlargement, rotation, etc., can be used as an interim measure. Surveillance of WRMDs (including the use of health-care-provider reports) can aid in identifying high-risk workplaces, occupations, and industries and in directing appropriate preventive measures.[12]

Low Back Injuries

Occupational risk factors for low back injuries include manual handling tasks,[13] twisting,[14] bending,[17] falling,[15] reaching,[16] lifting excessive weights,[17,17,18] prolonged sitting,[18] vibration,[17,19] and job satisfaction.[20,21] Some nonoccupational risk factors for low back injury include obesity,[22] genetic factors,[23] and smoking. [24]

Control and prevention of job-related low back pain can be accomplished through the evaluation of jobs and the identification of job risk factors. Redesign of jobs can lead to the reduction of these risk factors and good job design initially will prevent back injuries. Multiple approaches such as job redesign, worker placement, and training may be the best methods for controlling back injuries and pain.[24]

B. Workforce

The NIOSH evaluation of this motorcycle manufacturing plant focused on the flywheel milling and assembly department, where milling, assembly and truing, and balancing of flywheels are done.

Pre-Intervention Evaluation

In January 1990, the plant employed about 500 workers and produced approximately 253 motorcycle engines and 170 motorcycle transmissions each day. There were 38 full-time workers in the flywheel milling department. Production was 24 hours per day, with two-to-three employees per shift working in the milling area and another five e mployees assembling, truing, and balancing the flywheels. Employees rotated through the truing task every 2-to-4 hours. Occasionally, these employees may have worked 10-to-12 hour days to keep pace with production demands.

Post-Intervention Evaluation

In August 1993, the plant had increased employment and production by about 40% to about 700 hourly workers and produced approximately 340 motorcycle engines and 254 motorcycle transmissions a day. The flywheel milling department increased to 48 employees with two to three employees working in the milling area and seven assembling, truing, and balancing flywheels. Because of changes to the truing area (described below), employees did not need to be rotated.

C. Process Description

Milling of the flywheels consists of a series of steps: manually removing the flywheel from a supply cart; drilling and machine milling it; grinding off metal burrs; and inspecting, measuring, and placing the finished flywheel in a receiving cart. Each milling "cell" contains three to four milling machines, a drill press, and two-to-three worktables. Approximately two-three lbs. of metal are cut from each flywheel during the milling process.

After milling, the next phase is assembly of the flywheel unit. These components consisting of the gear and sprocket side of the flywheel, two connecting rods, bearings, and a crank pin, are assembled and sandwiched together by a "marriage press." After this, the unit is taken to the truing area for straightening and centering.

Truing of the flywheel was formerly done manually by mounting it on a fixture on top of a table, and manually rotating the flywheel to determine misalignment (a centering gauge is viewed by the operator to determine misalignment). In the initial NIOSH evaluation, when the misalignment area was found, the employee repeatedly struck the flywheel with a 5-pound brass-head hammer to straighten and center (true) the unit. In the follow-up evaluations, a 40-ton press performed the truing operation, and the hammers were eliminated. After the flywheel unit is trued, it is manually lifted and placed onto a cart, which is moved to the balancing area.

Balancing the flywheel unit is done by lifting it from a cart and placing it in a cradle in the balancing machine. The flywheel connecting rods are attached to balancing arms which rotate the unit at high speeds. A computer determines where holes are to be drilled to provide balance when the flywheel unit is operating at high speeds. Following this procedure, the flywheel is manually moved from the balancing machine to a cart. The weights of fully assembled post-milled flywheels (sprocket and gear) and their components (bearings, crank pin, and two connecting rods) are: large (FL) 32.5 lbs. (34 lbs. maximum weight), and small (XL) 25.6 lbs (26 lbs. maximum weight). The finished flywheel units are then moved from this department to the engine assembly department.

III. DESIGN AND METHODS

NIOSH researchers conducted an initial evaluation in January 1990 and four follow-up evaluations (May, August, and October 1992, and August 1993). The evaluation of the flywheel milling department included, a review of OSHA 200 logs, informal interviews with employees, and an ergonomic evaluation of jobs in the flywheel milling area.

A. Ergonomic Evaluation

Initial Evaluation

An in-depth ergonomic evaluation of the flywheel milling area was conducted during the initial survey consisting 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. Two flywheel milling cells were evaluated.

Videotapes of the jobs were analyzed at regular speed to determine 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.

Time and motion study techniques were used for the first phase of job analysis.[25] *Work methods analysis* was used to determine the work content of the job.[26] The second phase of job analysis was to review the job for recognized occupational risk factors for WRMDs. These WRMDs risk factors include repetition, force, posture, contact stress, low temperature, and vibration.[27,28] In addition, biomechanical evaluation of forces which are exerted on the upper limbs, back, and lower limbs of the worker while performing the task also was performed.[29] 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.

After receipt of the initial NIOSH report in October 1990, the company conducted several meetings over a 1-2 year period to engineer out specific job hazards in the flywheel milling and assembly department. The meetings led to the systematic selection of equipment and process changes based on over 20 performance criteria. Some of these criteria were: reduction or elimination of the specific hazard (vibration from hand tools), user friendly controls, noise reduction, easy access for maintenance personnel, parts availability, cycle time, machine guarding, and machine durability.

Follow-up Evaluations

Four follow-up evaluations were conducted between May 1992 and August 1993. During these evaluations NIOSH researchers spoke with the safety director as well as the operators, managers and engineers involved in the redesign of the work processes in the flywheel department. An evaluation was also done on the changes made since the initial evaluation. Specific NIOSH activities during these follow-up evaluations included: (1) discussions with employees regarding changes in their job for musculoskeletal hazards, (2) videotaping the flywheel milling, truing, and balancing process, (3) reviewing company ergonomic committee activities on reducing job hazards in this department,
(4) presenting education and training sessions on ergonomics to plant supervisors, engineers, and workers, and (5) reviewing records on reports of cases of musculoskeletal disorders.

Incidence rates of musculoskeletal disorders (the number of new cases per 100 workers) between 1987 and 1993 were determined using the OSHA 200 logs. All musculoskeletal problems including such conditions as sprains, strains, tendinitis, and carpal tunnel syndrome involving the upper extremities, neck, and back recorded on the OSHA 200 log were included in this analysis. Since it is often difficult to determine from the OSHA 200 logs whether a musculoskeletal sprain or strain is due to acute or chronic trauma, all of these events were included. Musculoskeletal contusions, which are likely to be more acute events, were not included. Data on the number of lost and restricted workdays for each case were also tabulated.

Information on the total number of hourly employees for each year was obtained and used to develop incidence rates. The incidence of musculoskeletal disorders was calculated for each year and each area of the body. Additionally, severity rates were calculated by examining the rate of lost or restricted workdays and the median number of lost or restricted workdays per case.

IV. RESULTS

A. Ergonomic Evaluation

Table 1 summarizes the initial ergonomic recommendations for the flywheel milling area made by NIOSH researchers in January 1990, and the actions completed by the company by the last follow-up evaluation in August 1993. This table shows that several actions were taken to address concerns about musculoskeletal injuries in the flywheel milling cell. Pre- and post- ergonomic intervention activities for the milling, assembly and truing, and balancing areas are summarized below.

Milling

Pre-Intervention Evaluation: Milling of the large (FL) flywheel (average weight 19.0), and the small (XL) flywheel (average weight 16.0), consists of 37 steps for the FL flywheel, and 25 steps for the XL flywheel. It was estimated that 28,175 lbs of flywheels were manually handled for the FL flywheel, and 18,980 lbs for the XL flywheel per 8-hour day. These total weights were derived by multiplying the average weight of the milled flywheel (17.5 lbs FL, and 14.5 lbs XL) times the average number of times the flywheel was picked up (23 and 17, respectively), times the average number of flywheels milled per day (70).

Post-Intervention Evaluation: To reduce the amount of weight handled by the flywheel milling operators, and to increase production rates the flywheel milling job, as described in the pre-intervention section above, was divided into two milling cells. Also, instead of two flywheel castings for the left and right half (gear and sprocket sides) as in the initial NIOSH survey, there is one master flywheel casting weighing 17.5 lbs for the FL flywheel, and 13.5 lbs for the XL flywheel. From the FL and XL master castings, the left and right side of the flywheels are milled. In the first flywheel milling cell (Figure 1), 13 steps were required to complete the workcycle. The number of flywheels milled per 8-hour day was approximately 84, this represents 17,472 lbs handled per day for the FL flywheel, and 13,759 lbs for the XL flywheel. In the second flywheel milling cell (Figure 2), 9 steps were required to complete the workcycle. The number of flywheels milled per day for this cell also was approximately 84, representing 12,096 lbs for the FL, and 9,526 lbs for the XL flywheel handled per day. Because of the short cycle time for the second milling cell, the worker on this job also worked on the flywheel balancing job.

Table 2 summarizes the material handling results of the flywheel milling job before and after ergonomic interventions.

Hand-Arm Vibration Exposure

Pre-intervention evaluation: In addition to the potential overexertion injuries for manual handling of the flywheels in the milling cells, another concern was excess hand-arm vibration exposure from the use of a hand-held grinder to remove metal burrs from the flywheel. It was determined that approximately 20% of the job cycle was used for removing metal burrs. As noted in Table 1, recommendations were provided to reduce vibration exposure and improve job efficiency. Figure 3 shows a worker using the hand-held grinder.

Post-intervention evaluation: Vibration exposure was virtually eliminated with the purchase of a customized metal deburring machine. This machine was designed according to specifications from engineers and workers performing the job, and would automatically remove burrs with grinding media (stones) inside the unit (see Figure 4). The installation of this unit in the flywheel milling cell resulted in over a 90% reduction in hand-held grinders and a reduction from 20% of the work cycle to less than 1% (occasional touch up) for hand-held grinding operations. The deburring machine allowed the worker to move on to other work elements while this job was done, thus making the job more efficient, and reducing potential hazardous vibration exposure.

The cost of the deburring machine was over 200,000 dollars. To justify the costs over hand-held grinding, the company has established an evaluation program which incorporates the goal of sound engineering and production principles with ergonomic design. Table 3 lists the steps in which decisions and actions of plant personnel accomplished its goal as applied to the deburring machine.

Truing (Assembly and Centering)

Pre-Intervention Truing Evaluation: After milling, the flywheels are assembled together with connecting rods, bearings, and a crank pin. A marriage press is used to sandwich the parts into one unit. The flywheel unit is then "trued." After mounting the flywheel on a fixture, the flywheel unit is manually rotated, using a centering gauge to detect misalignment, the unit is struck using a 5-pound brass-head hammer held by the worker (see Figure 5). Depending on the amount of straightening necessary, the initial impact of the brass-head hammer can be as high as 92,000 lbs. Impact forces are reduced as the flywheel is straightened to specifications. The repeated forces needed to straighten the unit were somewhat traumatizing to the workers and they needed to be rotated from this job ever 2 to 4 hours. Engineers and workers were working on how to reduce exposure to this job when NIOSH researchers arrived during the initial visit in January 1990. NIOSH researchers agreed that the job needed to be changed to reduce the impact force stressors to the upper limbs.

Post-intervention Truing Evaluation: Recommendations to reduce exposure to this job (called the "hammer slammer" job by workers) resulted in the use of a 40 ton press that was modified, based on plant ergonomic committee input, for truing the flywheels (see Figure 6). The press completely eliminated the need for the brass hammers, thus eliminating mechanical trauma to the upper limbs from this task.

Biomechanical analysis of this job showed that there is a moderate risk for lifting the 34 lb. flywheel assembly from the tote bin to the Hess press machine (Figures 7 and 8), Table 4, and from lifting the flywheel from the worktable to the tote bin (Figures 9, and 10, Table 5). Using the NIOSH formula for manual lifting, it was determined that the weight should be no more than approximately 20 lbs for the majority of workers to safely perform this job. As shown in Tables 4 and 5, the two biggest factors which reduced the amount of weight that can be safely handled were the horizontal distance (from the worker's spine to where the hands lift the flywheel), and the amount of upper to lower body asymmetry (i.e., twisting) while the worker handles the flywheel. Because of this, the "safe" lifting limit changes at the origin of the lift, and the destination, 27.2 lbs, and 20.1 lbs respectively (Table 4), and from the worktable, to the tote bin, 28.9 lbs and 19.7 lbs. Therefore, it is prudent to take the lowest weight that can safely be handled from the beginning to the end of the work cycle.

Balancing

Pre-intervention Balancing Evaluation: After the flywheel unit is trued, the next step is balancing. This process involves manually picking up the flywheel from a cart, and placing it in a cradle in the balancing machine (see Figure 11). The flywheel connecting rods are attached to balancing arms which rotate the flywheel at high speeds. Balance sensors relay a profile of the units balance characteristics to a computer which determines where the holes are to be drilled. After the holes are drilled the flywheel unit is rotated once more for a final balance check. The flywheel is manually picked up from the balancing machine, and placed in a cart. The process is then repeated.

Post-intervention Balancing Evaluation: A similar procedure for balancing the flywheels is performed using the sensors and computer. However, because the flywheel unit is heavy, an overhead hoist mounted on an x-y trolley (gantry hoist) was used to lift the unit and place it in the balancing unit cradle (see Figure 12). Balancing is performed by the computer, and the gantry hoist is used once more to put the finished part back in the cart. Using the 1991 NIOSH lifting formula, it was determined that workers performing this job were occasionally at risk for back injury when manually handling the FL flywheel unit. From Figure 11, it was determined that when the flywheel unit is picked up a safe weight is approximately 30 lbs, and when it is placed in the balancing cradle the safe weight is approximately 21 lbs. The difference in safe lifting weights is mainly attributable to the location of the load in relation to the body when it is placed in the balancing cradle. Therefore, the hoist is an excellent engineering control to address this material handling problem. Table 6 summarizes the information used to determine the NIOSH Recommended Weight Limit (RWL) of 30 and 21 lbs.

B. Rates of Musculoskeletal Disorders

During the entire 7 years (1987-1993), in the entire production facility there was a total of 555 reports of work-related musculoskeletal disorders, which resulted in 6255 lost workdays and 3385 restricted workdays. This translates to an average of between two and three lost or restricted workdays per worker per year due to work-related musculoskeletal disorders. About 57% of the cases and 65% of the lost or restricted workdays involved the upper extremities (shoulder, elbow, arm, or hand) and 40% of the cases and 33% of the lost or restricted workdays involved the back.

Table 7 shows the yearly incidence rates (the percent of workers reporting a new case each year) of musculoskeletal disorders for the entire production facility, as well as specific rates for the most commonly affected body parts: shoulder, hand/arm, and back. During the four year period (1990-1993) of development and implementation of an ergonomics program at this facility, the incidence rate of musculoskeletal disorders has decreased from 17% to 13%.

Figure 13 shows the increase in the number of hourly workers and the change in incidence rates between 1987 and 1993. Earlier in the 1980's, Harley-Davidson experienced economic difficulties and had laid off some of its workforce. As production began increasing, experienced workers were recalled to work from layoffs. Eventually, in about 1988 or 1989 new and inexperienced workers were hired, which may, in part, explain the rise in cases at that time. Additionally, at that same time, a new nurse was hired who brought new vigilance to the reporting of musculoskeletal disorders.

Table 8 shows the yearly incidence rates for the flywheel milling department between 1987 and 1993. The table shows both the incidence rates for all cases and the incidence rates for only those cases which involved lost or restricted workdays. It also shows the severity rates (the number of lost or restricted workdays per 100 workers) and the median number of lost or restricted workdays per case.

Table 8 shows that in 1989, just prior to the initial request for help, there was a dramatic increase in the incidence rate. Aside from that year, the total incidence rates show no clear pattern of change. The rate of lost or restricted workday cases (the more serious cases), however, has been decreasing from 27% in 1989 to 12.5 % in 1993. Additionally, there has been a decrease in the severity of cases as measured by the number and rate of lost or restricted workdays. This pattern has been erratic, however, because in 1990, prior to the implementation of most of the changes there was a major decline in cases during that one year. This may be explained by a sudden increase of 20% in the size of the department's workforce. Since many of these were new workers, it is possible that during their initial months of employment either they underreported potential musculoskeletal problems or the musculoskeletal disorder developed gradually and did not become symptomatic until the following year.

This follows a pattern seen in other facilities following ergonomic interventions. Initially there may be an increase in the total number of reports of cases as workers become better educated about these problems. However, because of early identification and treatment combined with changes in workstation design, the severity of reported cases declines. Additionally, since many of the ergonomic changes have only recently been introduced, it may still be too early to measure the full impact of the ergonomic program.

V. DISCUSSION

The problem-solving approach used by this company was effective because it involved a team approach of employees, engineers, managers, and medical personnel. This resulted in a participatory approach in which all parties in the flywheel milling and assembly department contributed with their knowledge and experience. Examples of this were demonstrated in the elimination of 5-pound brass hammers by a 40-ton press in the flywheel milling and truing area, elimination of manual transportation of flywheel units to the balancing machine by an overhead hoist system, and elimination of hand held grinders by a spindle deburring machine.

The experience of implementing an ergonomics program at Harley-Davidson exemplifies several general issues about what it takes to sustain a successful ergonomics intervention effort. The first lesson was that problem solving usually includes a series of steps rather than one leap from the problem to a solution. Depending on the training and resources of the company, this process can be immediate or take months. In addition, resources needed to do the job can be nominal or very costly. Examples of the two extremes in this study are: raising the drill press to eliminate stooping while loading flywheels into its fixture (no costs), and purchasing a customized spindle deburring machine (over 200,000 dollars).

Another lesson was that successful ergonomic programs need to be sustained because of the dynamic nature of today's business and production environment. Although a variety of approaches can achieve this, the company found that outside experts were helpful in assessing ergonomic changes, providing stimulus, and acted as a catalyst to move things along. The outside expert proved to be effective on the planning side of the equation, so that ergonomic factors could be engineered into the machines and processes prior to operation. Retrofitting machinery can be very costly compared to engineering ergonomics into original machine design.

The third lesson was understanding the importance of the front line supervisor who serves as the communicator between management and the production worker. The front line supervisor can make or break an ergonomics program. The supervisor provides a supportive environment for worker ideas, and enhances their concepts into practical applications using sound engineering principles. The front line supervisor also needs to effectively communicate with upper management to present needs in a systematic way, and secure resources to get the job done right.

The goal of an effective ergonomic intervention effort is to eliminate the job hazards. At Harley-Davidson this was accomplished through a process where there was commitment from top management to provide resources to manufacture flywheels better and more safely, from company engineers to select the most cost-effective equipment available, and from workers to be involved in every aspect of the equipment from selection to custom design. Because the process of ergonomic changes involved the employees as well as management, and because the employees were involved in all phases of the ergonomics process, it is believed that Harley-Davidson should be used as a model for other industries which have high morbidity from poorly designed jobs.

VI. RECOMMENDATIONS

A. Engineering Controls

Flywheel Milling

1. While the amount of flywheel material has been reduced significantly (from over 28,175 lbs to 17,472 lbs for FL flywheels), during this intervention evaluation, production has increased 7 to 10 % per year. With the combination of higher production, and incentive pay for working above 100%, workers will likely increase the total amount of flywheel material handled over time. Because of this, it is suggested that the ergonomic team think about how to further optimize flywheel throughput with the least amount of manual handling. Some possible ways of accomplishing this include: gravity conveyers, optimal positioning of worktables and machines to reduce travel distances, and orienting machines so that flywheels are positioned at chest level, and close to the body.

2. Plastic separators to separate flywheels in tote carts should be readily available. Flywheel separators should be used for both incoming and outgoing stock. Make sure there are enough plastic separators in the system for the suppliers. Consider bar codes for the separators, and encourage the operators to use the new light pen system located near their workstations to electronically scan the bar code and call for more separators when they get low.

3. The workers should keep the work area as clear as possible. All worktables in the milling area should have purpose, and be positioned so they help with throughput.

4. Rubber matting should be kept in good repair, and be replaced periodically to maintain good cushion and support for the worker.

Assembly and Truing Flywheels

1. Install an overhead hoist for moving the flywheel to and from the marriage press and 40-ton Hess press during truing operations. Because of overhead barriers, consider a counter balancing device and articulating arm to overcome these barriers.

2. There is excess manual material handling from moving the flywheel unit back and forth between the Hess press and an adjacent work table used for additional measurements. Consider integrating the two operations. If

this is not possible, consider installing a swing arm with this measuring device attached. The swing arm can be pivoted next to the Hess press and the flywheel unit can be moved easier.

Flywheel Balancing

1. Install an adjustable height wooden workbench to optimize biomechanical leverage for reaming holes in flywheels. The current workbench is approximately 5-6 inches too high for the operator who is approximately 6'4" tall.

B. Work Practices

Flywheel Milling

1. Workers should be trained to organize their work station to optimize movement and function. This can be done when tote carts, and tables, can be moved into position by the worker. This is especially helpful, when the same machines are operated by different workers.

Flywheel Balancing

1. Encourage operators to use a hoist, especially when placing and removing the flywheel unit from one balancing machine. Machinery and palm button controls require operator to over reach when manually putting flywheel unit into balancing cradle. Because of this, education and training of workers in using the hoist is recommended.

C. Organizational

1. Develop a written ergonomics program based on the approach used in Department 909, and consider using personnel from this department to demonstrate how they solved problem jobs and engineered ergonomics and good work practices into new jobs. Videotaping the workers and providing narratives to this process may make it cost effective for the company. The videotape can be used as an orientation for new employees, and for other departments as a place to begin their own program.

2. Consider sit/stand chairs to offer temporary relief from standing between work cycles when machines are performing work in this department.

3. Worker designed caliper set holder in the flywheel milling cell #1 should be showcased as an example of good ergonomic design by the worker and the tool department. The holder serves the worker

   in making it easy and convenient to access measuring tools for quality control.

D. Medical Surveillance

Develop a medical surveillance program which monitors musculoskeletal disorders in the plant. The ergonomic program and training of plant personnel have raised awareness of job hazards and early reporting of musculoskeletal discomfort is expected. Because of the dynamic nature of manufacturing in this plant, job hazards may vary depending on production demands, quality of parts, and maintenance of machines and tools. Early detection of problems will complete the communication cycle between workers and management to avoid more serious musculoskeletal disorders and to develop priorities for where ergonomic intervention efforts should be focussed.

E. Other

Air hoses used to remove excess oil from the parts should be used with care. When the nozzle is held too close to the flywheel to remove the oil, it can generate oil aerosols which may cause both acute and chronic health problems.

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VIII. AUTHORSHIP AND ACKNOWLEDGEMENTS

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IX. DISTRIBUTION AND AVAILABILITY

Copies of this report have been sent to:

1. Harley-Davidson Incorporated
2. United Paper Workers International Union, Local 7209

For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

Table 1
Evaluation of Ergonomic Changes
HETA 91-0208-2422 Harley-Davidson Incorporated

Engineering Changes

Initial Recommendation (January 1990)	Result (August 1993)
Reduce the weight of the flywheels by improving die-cast specifications. This will reduce milling time and the amount of weight handled over the workday.	Weight of fly wheels were reduced from nearly 2 lbs by improving die-cast specifications. In addition, only one type of flywheel casting (for the gear and sprocket sides) is shipped to plant, and is milled to specifications. This simplifies the milling process, reduces waste, and multiple handling of flywheels.
Reduce or eliminate exposure to vibration from powered hand grinder. Twenty percent of the work cycle time consists of vibration exposure from this tool.	Customized metal deburring machines were purchased to eliminate over 90% of the exposure from the hand grinding operations. The hand grinder is used less than 1% of the work cycle time (for minor touch up of fly wheel).
Layout of the flywheel milling job is inefficient from a production and material handling perspective. Consider movable flywheel carts and/or gravity conveyors between milling work stations to reduce musculoskeletal stress.	The Flywheel milling cell was reorganized into 2 work cells, reducing the number of machines per cell, and the amount of material handled per worker. For the FL flywheel, this resulted in a 38% reduction in material handling from 28,175 lbs to 17,472 per shift, and a 43% reduction in the number of times the operator needed to handle the flywheel during the milling process. Similar results were documented for the XL flywheel milling process.
Reduce the size of the metal pan that is built around the base of the indexing machine and round the corners to reduce the reach distance to attach the flywheels to the machine.	The indexing machine has been eliminated, and replaced by the another more efficient machine. Physical barriers were considered and designed out of the new machine before it was put into operation.
Install durable rubberized floor matting around flywheel milling cells to reduce lower limb fatigue of workers.	Several types of rubberized floor matting were evaluated for durability, slip-resistance, and comfort by the operators in this department. A selection of rubberized mats were made available for the operators.
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.	Most physical barriers were eliminated because the worker was part of the workstation redesign process. Toe and leg space were considered when the work cells were redesigned. Machines, such as the drill press, were adjusted up to chest height of worker. This reduced stooping to position the flywheels in the machines.

Table 1 (Cont.)
Evaluation of Ergonomic Changes
HETA 91-0208-2422 Harley-Davidson Incorporated

Work Practices

Initial Recommendation (January 1990)	Final Result (August 1993)
Recommend workers use the "power grip" rather than the "pinch grip." when handling the flywheel. The "pinch grip" requires handling of the flywheel by the fingertips and thumb, resulting in high musculoskeletal forces and fatigue. Use of two hands is also recommended when handling parts to reduce asymmetric biomechanical loading of the limbs and back.	All of the workers in this department received ergonomics training on material handling techniques. When the flywheels were handled at the wheel end, both hands were used, especially when positioning flywheels in or out of the milling machines.
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.	The wheel carts bumpers were retrofitted with tubular steel to reduce mechanical contact with the worker's shins. Several of the wheel carts were also fitted with hinged bumpers that can be manually rotated in the vertical position and out of the worker's way. Workers position the wheel carts close to their work area to reduce distance and material handling.
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.	On-site training of workers about biomechanical aspects of work may have increased their awareness to reduce overreaching while performing their job. Redesign of the workstation also helped reduce overreaching by providing leg and toe clearance, and adjusting the height of the workstations to fit the worker.

Table 2.
Comparison of Pre- and Post- Interventions of Manual Handling of Flywheel Milling
HETA 91-0208-2422 Harley-Davidson Incorporated

Pre-intervention (January 1990)	**Fl-Flywheel**	**Xl-Flywheel**
Premilled Flywheel Weight	19.0	16.0
Average Weight	17.5	14.5
Average Cycle Time	5 minutes	4 minutes
# Flywheels/8-hr shift	70	75
# Steps Moving Flywheel	23	17
# lbs. Moved/8-hr shift	28,175	18,980
Post-Intervention First Flywheel Cell[1] (August 1993)		
Premilled Flywheel Weight	17.5	13.5
Average Flywheel Weight	16.0	12.6
Average Cycle Time	4 minutes	4 minutes
# Flywheels/8-hour shift	84	84
# Steps Moving Flywheel	13	13
# lbs. Moved/8-hour shift	17,472	13,759
Post-Intervention Second Flywheel Cell[2]		
Average Weight Flywheel	16.0	12.6
Average cycle time	1.5 minutes	1.5 minutes
# Flywheels/8-hour day	84[3]	84
# Steps Moving Flywheel	9	9
Average Weight/8-hour day	12,096	9,526

1. Flywheel milling completed by another worker in adjacent cell.
2. Second flywheel cell completes the milling process.
3. Up to 280 flywheels can be milled per 8-hour day. However, this worker also does flywheel balancing job and only keeps pace with the first flywheel milling cell.

Table 3
Steps in the Flywheel Deburring Machine Purchase
HETA 91-0208-2422 Harley-Davidson Incorporated

Steps	Activity	Comments
1.	NIOSH report (January 1990), observes potential problem from hand-arm vibration exposure from hand-held grinder.	Recommends several options to reduce exposure, including a metal finishing machine to remove burrs.
2.	Problem solving team formed by the company.	Team participants: Manufacturing engineer -1, operators -2, maintenance machine repairman -1, supervisor -1, tool designer -1, medical -1, purchasing -1, and facility -1.
3.	Mission Statement formed.	"Deburr flywheels and connecting rods in a manner to decrease musculoskeletal injuries from hand grinders, while improving quality and reducing variability."
4.	Overview of Method.	1. Three vendors quoted project; 2. team ran trials with all three and rated results on a matrix; 3. one vendor received highest quality matrix rating and also received a consensus favorable rating from the team.
5.	Definition of Priorities	1. "What the customer wants." (safety, quality, ergonomics); 2. How the company can meet these requirements: (a) reduce hand grinding > 90%, (b) machine construction, (c) ease of load and unload.
6.	Analysis Methods	1. Trials and analysis; 2. interview of vendors; 3. discussion and review of machine and process details.

Table 3 (cont.)
Steps in the Flywheel Deburring Machine Purchase
HETA 91-0208-2422 Harley-Davidson Incorporated

Steps	Activity	Comments
7.	Justification	1. Safety: (a) eliminate flywheel grinding by 90%, (b) estimated savings from prevented lost-time accidents $53,679 (1987-1991). 2. Quality, same or improved - no loose burrs, reduced variability, complexity, increase throughout. 3. Ergonomic, (a) easy to load and unload, (b) no forward bending, especially with weight out in front of body, (c) both hands available to handle flywheels. 4. Housekeeping and environmental, (a) noise cover, (b) eliminates flying metal.
8.	Delivery and Payback Impacts	(a) headcount - meets planned requirements for future layout and schedule production increases, (b) meets capacity effect with less increased manual time, (c) cycle time less than 2 minutes/flywheel, 20 seconds to load and unload, (d) labor cost savings - none except cost increase avoidance savings with increases in schedule, (e) flexibility - increased, (f) set-up less than 10 minutes, (g) in-process inventory, (h) floor space - more than hand grinders; same for alternatives, (i) overhead - increased. annual usage cost saved (grinders and bits $1,730, new process annual costs $7,848)
9.	Employee modification recommendations	(a) Install insulation covers to reduce noise, (b) install load arms to reduce bending over to manually load flywheels, (c) add rinse cycles to clean flywheels.
10.	Costs	$229,616
11.	Timetable	Delivery (12-23-92), Installation 1-11-93), Implementation (6-14-93).

Table 4
Calculations Using 1991 NIOSH Lifting Formula[1] For Flywheel Truing Machine Operator Task 1
HETA 91-0208-2422 Harley-Davidson Incorporated

Job Analysis Worksheet

Department: 909 — Job
Truing Machine Operator — Pick Up Flywheel from Tote Cart
Date: August 30, 1993

Step 1. Measure and record task variables

Object Weight (lbs)		Hand Location (in)				Vertical Distance (in)	Asymmetric Angle (degrees)		Freq. Rate	Duration	Object Coupling
		Origin:See Figure 7		Dest.:See Figure 8			Origin	Dest.	lifts /min	Hours	
L(avg)	L(Max.)	H	V	H	V	D	A	A	FM		CM
32	34	15	40	20	50	10	30	0	< .2	< 2	Fair

Step 2. Determine the multipliers and compute the Recommended Weight Limits (RWL's)

RWL = LC x HM x VM x DM x AM x FM x CM

ORIGIN RWL = 51 x .67 x .93 x 1.0 x .90 x .95 x 1.0 = 27.2 lbs

DESTINATION RWL = 51 x .50 x .85 x 1.0 x 1.0 x .95 x 1.0 = 20.1 lbs

Step 3. Compute the LIFTING INDEX

ORIGIN Lifting index = Object Weight / RWL = 34/27.2 = 1.25

DESTINATION Lifting index = Object Weight / RWL = 34/20.1 = 1.69

[1] See Appendix A for Calculation for the NIOSH lifting formula.

Table 5
Calculations Using 1991 NIOSH Lifting Formula[1] For Flywheel Truing Machine Operator Task 2
HETA 91-0208-2422 Harley-Davidson Incorporated

Job Analysis Worksheet

Department: 909
Job Title: Truing Machine Operator
Date: August 30, 1993

Job Description: Pick Up Flywheel from Work Table

Step 1. Measure and record task variables

Object Weight (lbs)		Hand Location (in)				Vertical Distance (in)	Asymmetric Angle (degrees)		Freq. Rate	Duration	Object Coupling
		Origin: See Figure 9		Dest.: See Figure 10			Origin	Dest.	lifts /min	Hours	
L(avg)	L(Max.)	H	V	H	V	D	A	A	FM		CM
32	34	15	45	22	35	10	0	20	< .2	< 2	Fair

Step 2. Determine the multipliers and compute the Recommended Weight Limits (RWL's)

RWL = LC x HM x VM x DM x AM x FM x CM

ORIGIN RWL = 51 x .67 x .89 x 1.0 x 1.0 x .95 x 1.0 = 28.9 lbs

DESTINATION RWL = 51 x .45 x .96 x 1.0 x .94 x .95 x 1.0 = 19.7 lbs

Step 3. Compute the LIFTING INDEX

ORIGIN Lifting index = Object Weight / RWL = 34/28.9 = 1.17

DESTINATION Lifting index = Object Weight / RWL = 34/19.7 = 1.73

[1] See Appendix A for Calculation for the NIOSH lifting formula

Table 6
Calculations using 1991 NIOSH Lifting Formula[1] for Flywheel Assembly Lift for Balancing Job.
HETA 91-0208-2422 Harley Davidson Incorporated

Job Analysis Worksheet

Department: 909
Job Description:
Job Title: Balancer
Load Flywheel Unit into
Date: August 30, 1993
Balancing Machine

Step 1. Measure and record task variables

Object Weight (lbs)		Hand Location (in)				Vertical Distance (in)	Asymmetric Angle (degrees)		Freq. Rate	Duration	Object Coupling
		Origin		Dest. See Figure 11			Origin	Dest.	lifts /min	Hours	
L(avg)	L(Max.)	H	V	H	V	D	A	A	FM		CM
32	34	15	40	20	35	5	0	30	< .2	< 2	Fair

Step 2. Determine the multipliers and compute the Recommended Weight Limits (RWL's)

RWL = LC x HM x VM x DM x AM x FM x CM

ORIGIN RWL = 51 x .67 x .93 x 1.0 x 1.0 x .95 x 1.0 = 30 lbs

DESTINATION RWL = 51 x .50 x .96 x 1.0 x .90 x .95 x 1.0 = 21 lbs

Step 3. Compute the LIFTING INDEX

ORIGIN Lifting index = Object Weight / RWL = 34/30 = 1.13

DESTINATION Lifting index = Object Weight / RWL = 34/21 = 1.62

[1] See Appendix A for Calculation for the NIOSH lifting formula.

Table 7
Entire Production Facility
Incidence Rates of Musculoskeletal Disorders from OSHA 200 Logs
HETA 91-0208-2422 Harley-Davidson Incorporated

Year	Total Rate (% of workers)	Shoulder Rate (% of workers)	Hand/Arm Rate (% of workers)	Back Rate (% of workers)
1987	9	3	2	3
1988	10	1	4	4
1989	14	1	5	6
1990	17	5	5	7
1991	17	4	3	7
1992	16	3	4	6
1993	13	3	3	4

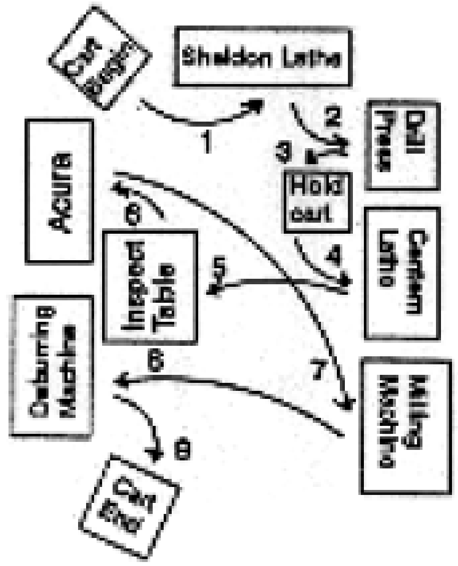
Table 8
Flywheel Department
Trends in Work-Related Musculoskeletal Disorders 1987-1993
HETA 91-0208-2422 Harley-Davidson Incorporated

Year	Workers	WRMD[1] Incidence Rate (% of Workers)		Lost/Restricted Workdays	
		Total	Lost/Restricted Workday Cases	Number per 100 Workers	Median # per Case[2]
1987	34	17.6	11.8	110	10
1988	34	11.8	8.9	130	13
1989	36	38.9	27.6	610	13
1990	44	20.5	11.5	390	33
1991	43	27.9	18.7	480	21
1992	45	17.8	13.4	560	12
1993	48	20.8	12.5	190	11

[1] Work-related Musculoskeletal Disorders-Includes all neck, upper extremity and back cases.
[2] This includes only those cases that had some lost or restricted workdays.

Figure 1

Flywheel Milling Job #1



Figure

Flywheel Milling Job #2

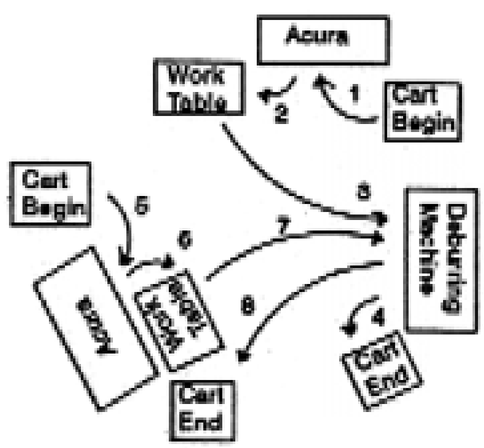


Figure 3.
Worker in Flywheel Milling job using a hand-held grinder

Figure 4.
Worker in Flywheel Milling positioning a flywheel on deburring machine robot arm.

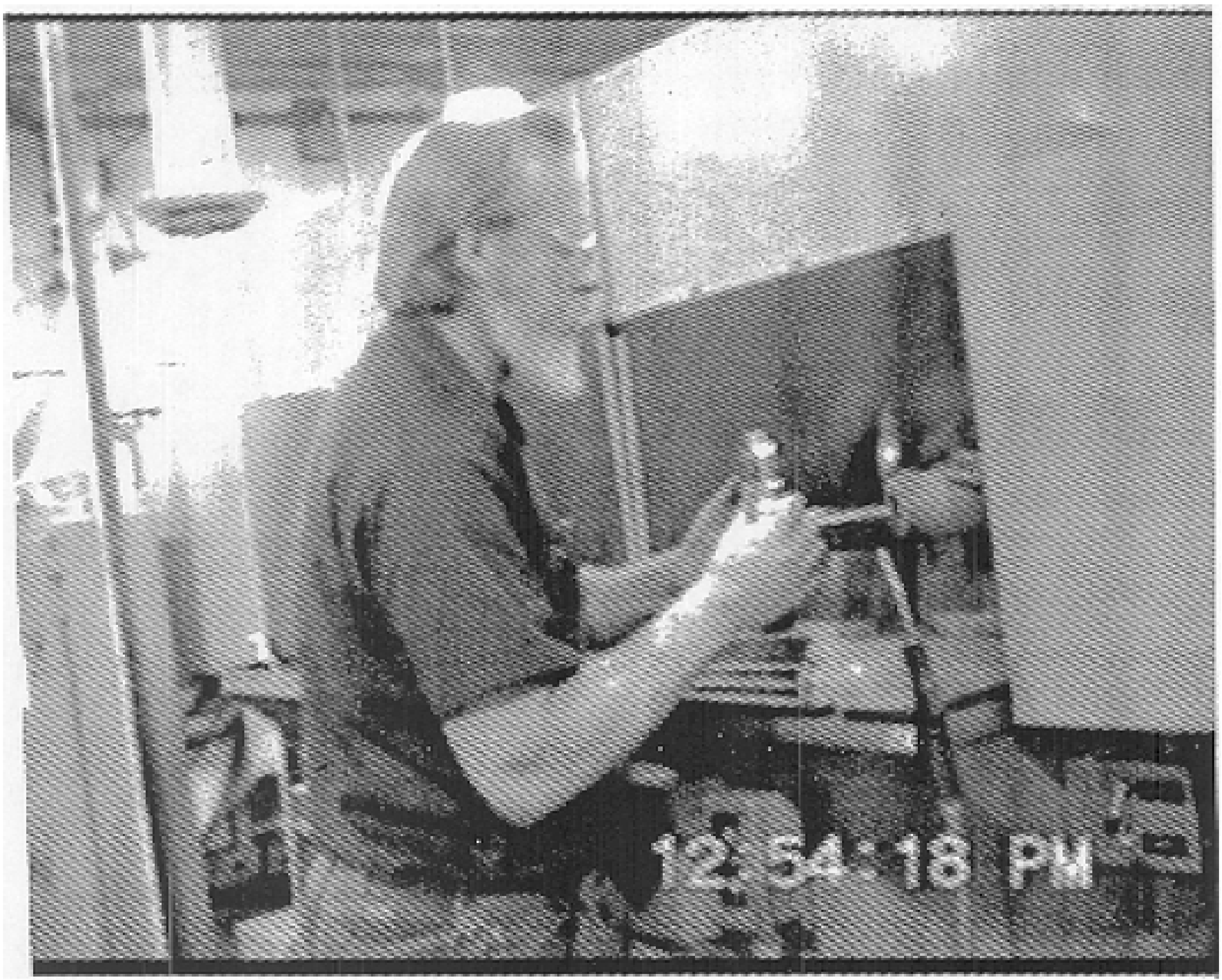


Figure 5.
Flywheel truing operations using 5-pound brass-head hammer.

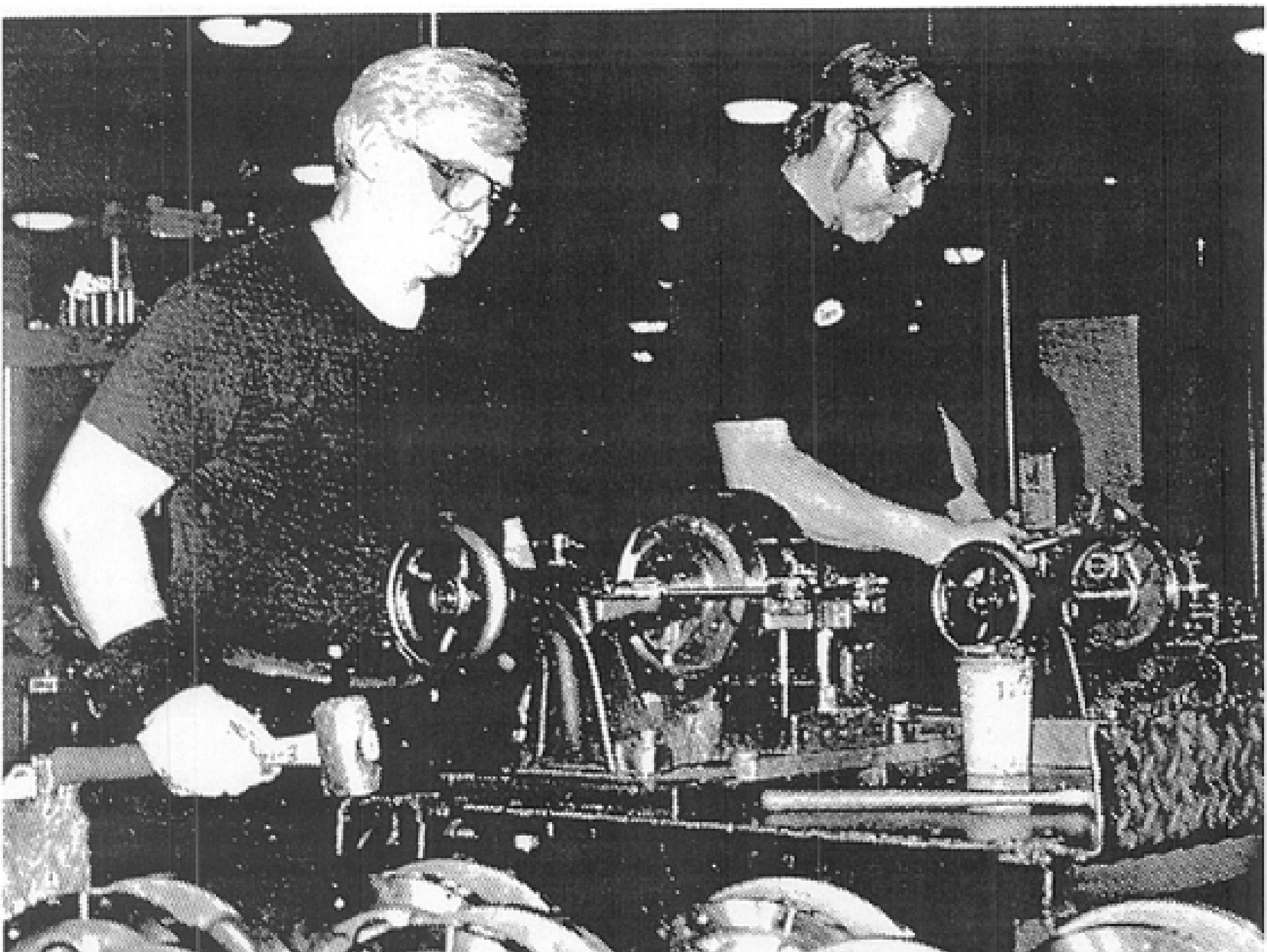


Figure 6.
Flywheel truing operations using a 40 ton press.

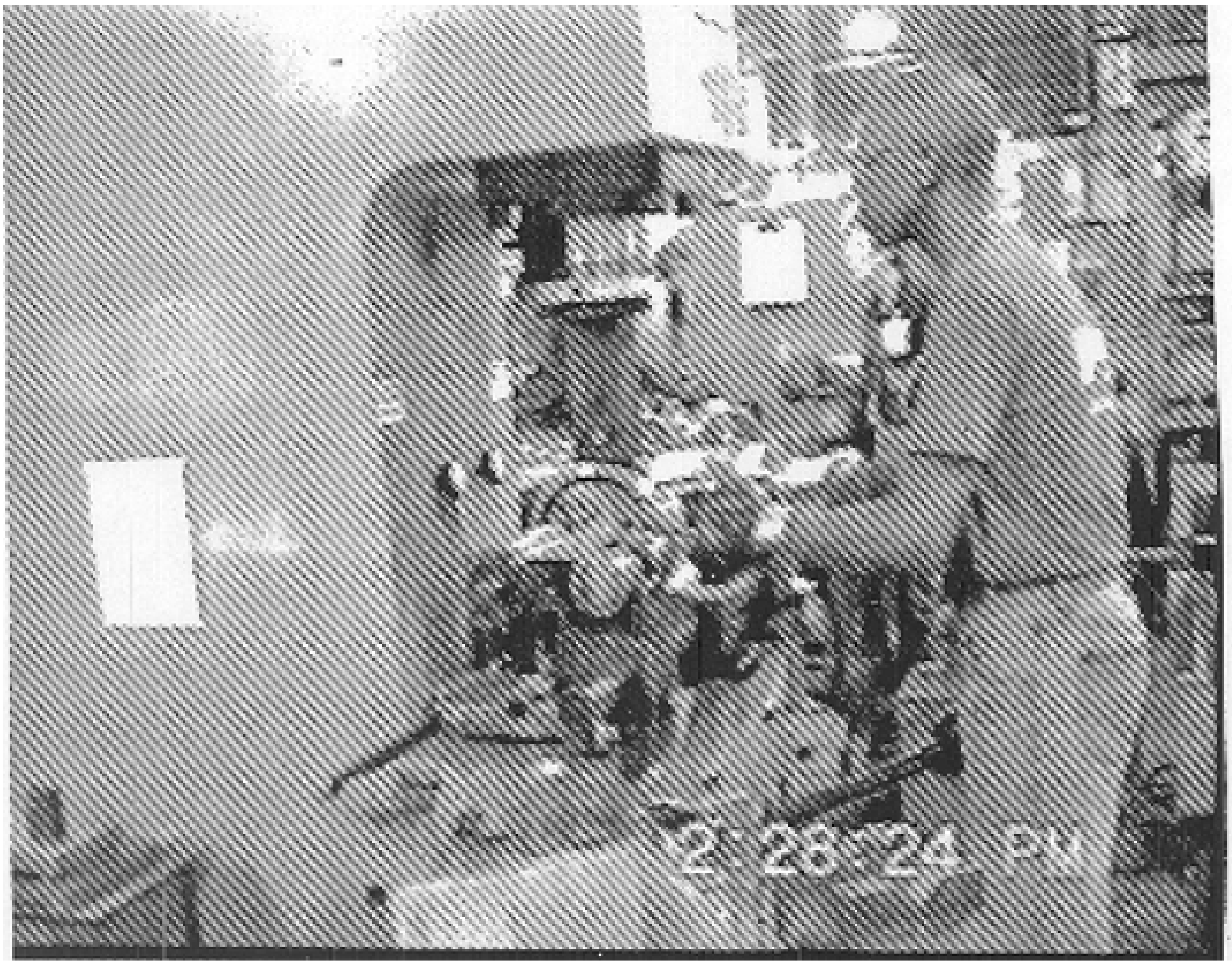


Figure 7
Worker lifting flywheel assembly from tote bin to truing press.

Figure 8.
Worker lifting flywheel assembly from truing press.

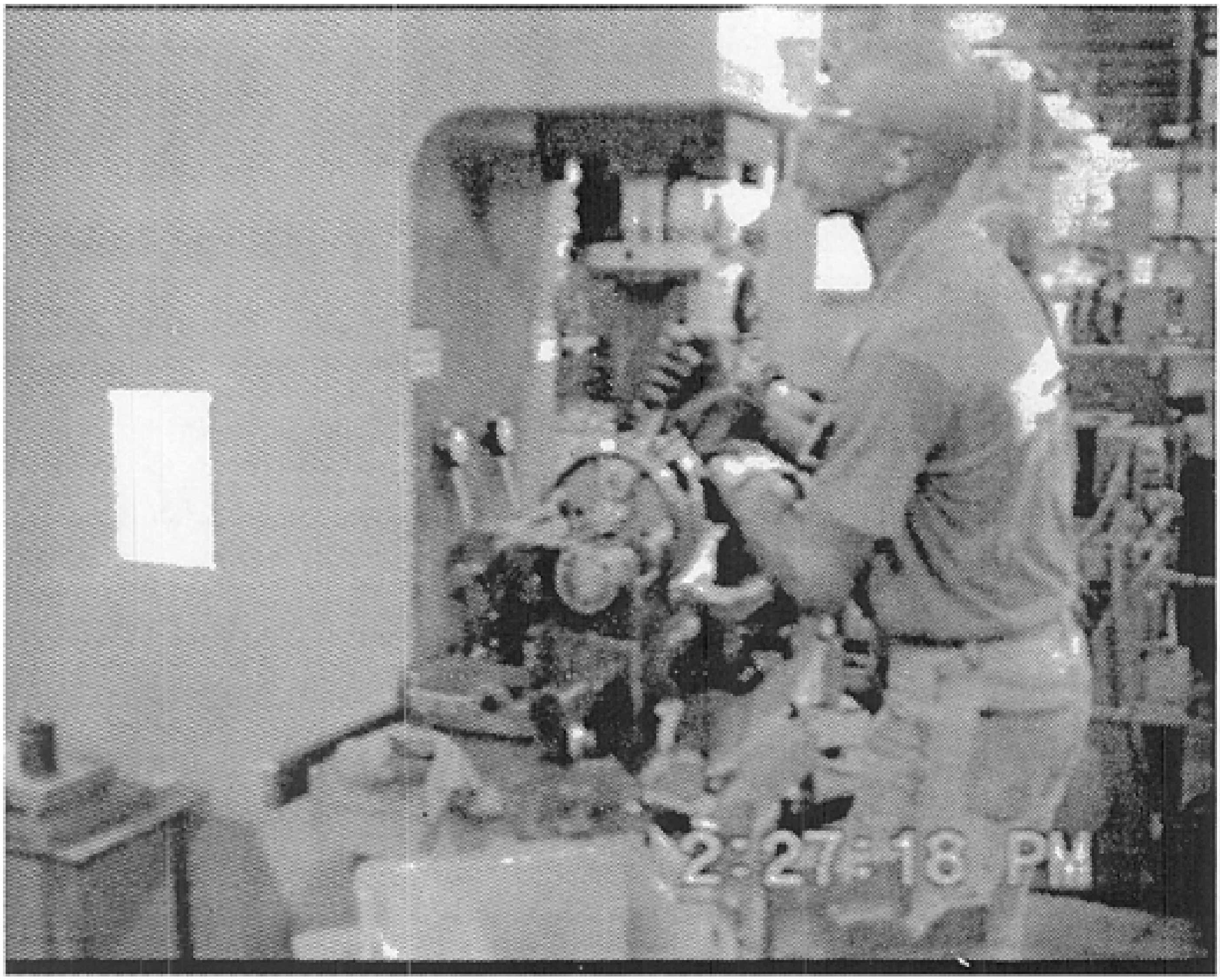


Figure 9.
Worker placing flywheel assembly on worktable (truing area).

Figure 10.
Worker placing flywheel assembly in tote bin (truing area).

Figure 11.
Worker placing flywheel in balancing machine

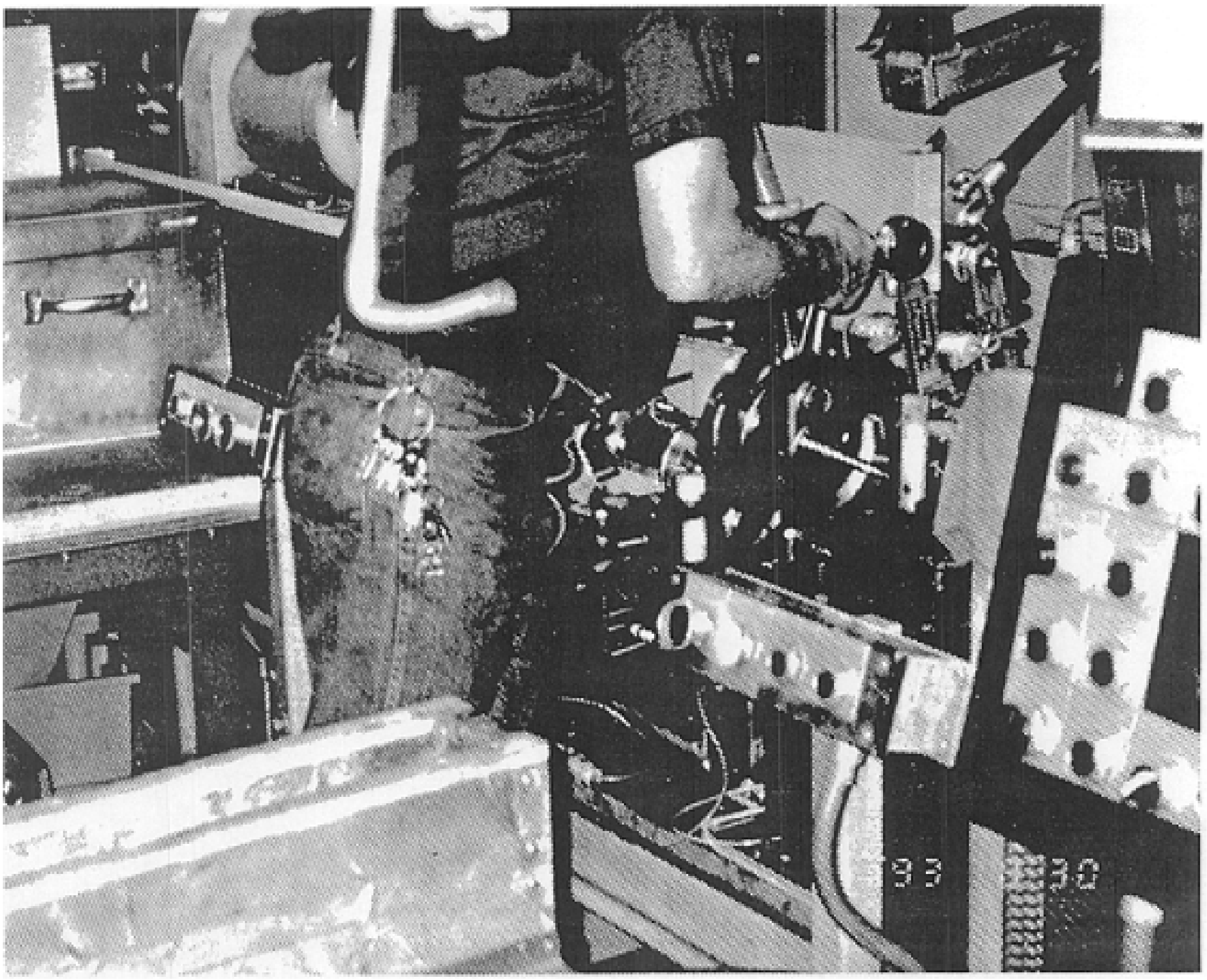
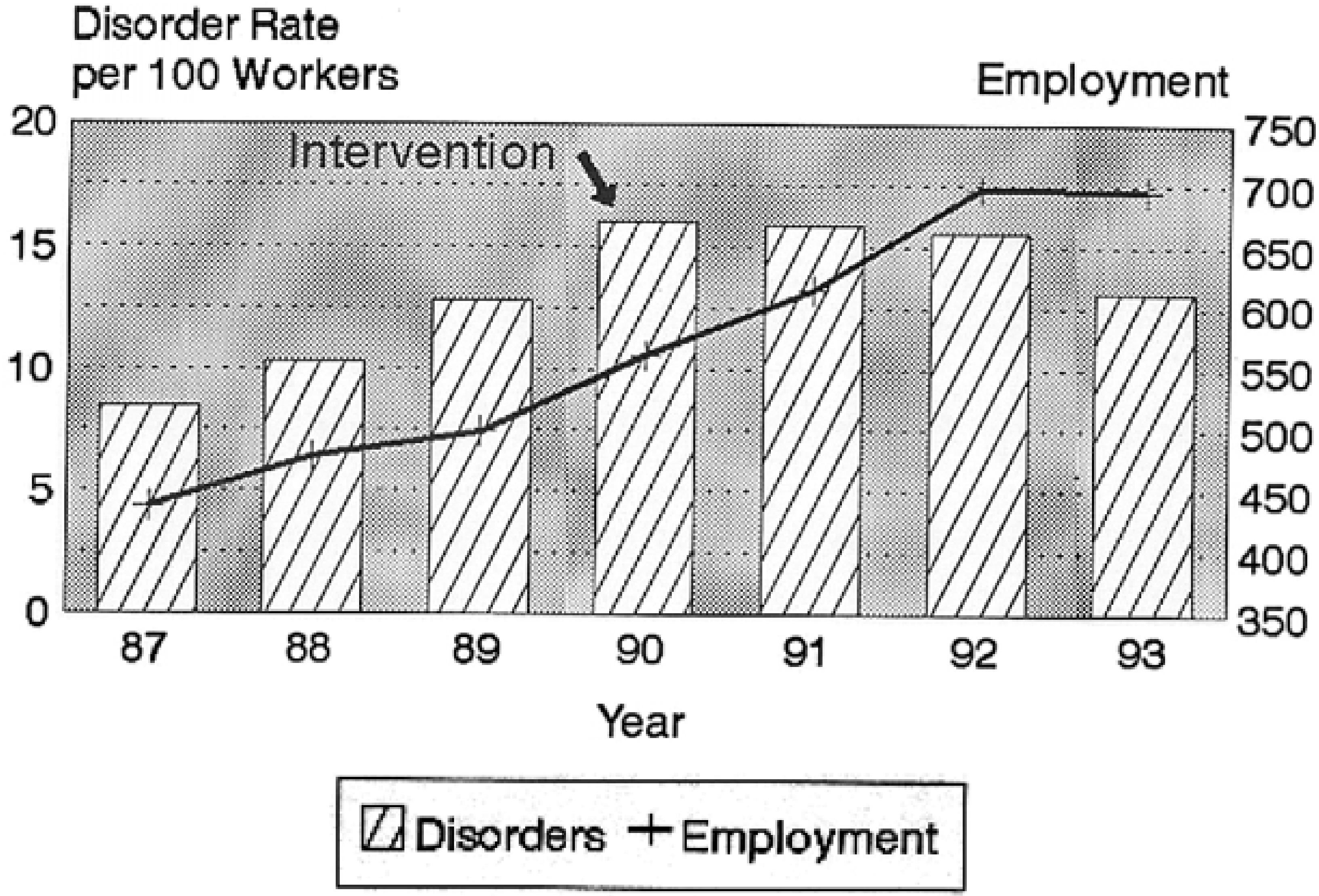


Figure 12
Overhead hoist moving flywheel to balancing machine

Figure 13
Employment Growth and Rates of Musculoskeletal Disorders



Appendix A
NIOSH Lifting Equation
HETA 91-0208-2422 Harley-Davidson Incorporated

Recommended Weight Limit (RWL) = LC * HM * VM * DM * AM * FM * CM
(* indicates multiplication.)

Component	METRIC	U.S. CUSTOMARY
LC = Load Constant 51 lbs	23 kg	
HM = Horizontal Multiplier (10/H)	(25/H)	
VM = Vertical Multiplier	$(1-(.003\|V-75\|))$	$(1-(.0075\|V-30\|))$
DM = Distance Multiplier	(.82+(4.5/D))	(.82+(1.8/D))
AM = Asymmetric Multiplier	(1-(.0032A))	(1-(.0032A))
FM = Frequency Multiplier	(from Table 1)	
CM = Coupling Multiplier	(from Table 2)	

Where:

H = Horizontal location of hands from midpoint between the ankles. Measure at the origin and the destination of the lift (cm or in).

V = Vertical location of the hands from the floor. Measure at the origin and destination of the lift (cm or in).

D = Vertical travel distance between the origin and the destination of the lift (cm or in).

A = Angle of asymmetry - angular displacement of the load from the sagittal plane. Measure at the origin and destination of the lift (degrees).

F = Average frequency rate of lifting measured in lifts/min.Duration is defined to be: $\leq$ 1 hour; $\leq$ 2 hours; or $\leq$ 8 hours assuming appropriate recovery allowances (See Table 1).

Appendix A

Table 1
Frequency Multiplier (FM)
NIOSH Lifting Equation

Frequency Lifts/min	Work Duration					
	≤ 1 Hour		≤ 2 Hours		≤ 8 Hours	
	V < 75	V ≥ 75	V < 75	V ≥ 75	V < 75	V ≥ 75
0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
>15	.00	.00	.00	.00	.00	.00

†Values of V are in cm; 75 cm = 30 in.

Appendix A

Table 2
Coupling Multiplier
NIOSH Lifting Equation

Couplings	V< 75 cm (30 in)	V ≥ 75 cm (30 in)
	Coupling Multipliers	
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90