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Square D Company
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I. SUMMARY

On March 29-30, 1993, NIOSH investigators conducted a health hazard evaluation at the Square D Company, a manufacturer of instrument transformers in Clearwater, Florida. Company management had requested an ergonomic evaluation of the high-voltage winding and taping department. They were particularly interested in recommendations for engineering controls to prevent work-related musculoskeletal disorders (WMSDs).

The ergonomic assessment consisted of three parts: (1) measurements and videotape recordings of the work layout, workstation configuration, and types of tools used; (2) laboratory analyses of videotapes of specific work activities to identify and characterize contributing factors to musculoskeletal problems; and (3) development of engineering and administrative recommendations to prevent and control WMSDs.

For the laboratory analyses, the Ovako Working-Posture Analyzing System (OWAS) was used to classify high-risk postural loads affecting the back, neck-and-shoulder area, and legs; and the Armstrong postural classification method was used to provide a more detailed assessment of the shoulders, elbows, wrists, and hands. Recommendations for engineering controls to reduce extreme joint movement, muscle effort, and repetitive movements were derived from the laboratory analyses.

The medical assessment included confidential interviews with 19 (70%) of the 27 employees at work in the department at the time of the site visit and a review of the Occupational Safety and Health Administration (OSHA) Forms 200 (Logs and Summaries of Occupational Injuries and Illnesses) for the previous five years.

The OWAS whole body assessment showed that winding jobs have the potential for inducing significant neck, back, and leg stress related to an assembler's height, the lack of vertical adjustability on the winding machine, the assembler's standing position, and use of the foot pedal. The OWAS analysis showed that wrapping and taping jobs may pose a moderate risk for WMSDs of the back, shoulders, and arms related to bending forward at the trunk, reaching in and around the core, and the lack of easy vertical adjustability of the jigs. Evaluation of wrapping and taping jobs by the Armstrong method showed a potential for WMSDs related to the moderate-to-high shoulder, arm, and wrist deviations. During set-up at the stem-taping station, the potential for risk of back injury is related to the various weights and shapes of the transformer units and the spinal stress related to mounting and dismounting the units while bending forward at the trunk. Although kit preparation was designated a light-duty assignment, the required activities have the potential for inducing stress to an employee's upper extremities. Risks for WMSDs in this

work area are related to the use of high grip-force exertions, maintenance of static postures, handling of large rolls of paper, and lack of chair adjustability at the cutting machine. Some kit-preparation activities may still be too stressful for employees treated with surgeries for carpal tunnel syndrome or ganglion cyst, and could prolong recovery time.

Seventeen (89%) of the interviewed employees, including seven (78%) of the nine randomly selected employees, reported musculoskeletal symptoms. Almost two-thirds of the interviewed employees reported hand-wrist symptoms. Eleven (92%) of the twelve employees who reported hand-wrist symptoms related their symptoms to pulling paper or wrapping and taping. Two of these workers were assigned to the kit-preparation area for restricted duty because of hand-wrist problems. Fourteen (74%) of the interviewed employees reported musculoskeletal symptoms in other parts of the body. Of the 17 employees who reported any symptom, a few stated that they did not seek medical attention because they did not think it would help. Review of the OSHA Forms 200 showed that approximately half of the employees in the department had reportable WMSDs over the 5-year period ending in 1992. Although no lost work days were reported during this time period, several employees had surgical treatments for WMSDs, and about one-third of the employees in the department had been on restricted work activities for more than one day. The number of days on restricted work activities was equivalent to 9 person-months for the 5-year period.

Because work in the department is basically self-paced, most of the WMSDs are probably related to assemblers' postures and movements during physical interactions with the products or machines. However, some employees reported problems related to work-pace standards, which could also contribute to the prevalence and severity of WMSDs in the department.

The findings of this health hazard evaluation indicate that assemblers in the high-voltage winding and taping department have a potential risk for WMSDs and that the prevalence of WMSDs among assemblers is more widespread than management originally suspected. Because WMSDs are related to multiple factors, successful prevention and control of WMSDs require a multifactorial approach. Recommendations include engineering controls, administrative controls, education and training, and a medical program. These measures should be integrated into an ergonomics program, with input from employees as well as consultants and management.

Keywords: SIC 3612 (Power, Distribution, and Specialty Transformers), transformer manufacturing and assembly, ergonomics, musculoskeletal disorders, cumulative trauma disorders, ganglion cyst (ICD-9 727.49), carpal tunnel syndrome (ICD-9 354.0).

II. INTRODUCTION

In November 1992, the National Institute for Occupational Safety and Health (NIOSH) received a management request for a health hazard evaluation at the Square D Company, a manufacturer of instrument transformers in Clearwater, Florida. Square D management requested an ergonomic evaluation of the high-voltage winding and taping department with recommendations for engineering controls to prevent work-related musculoskeletal disorders (WMSDs). NIOSH investigators conducted a site visit on March 29-30, 1993.

The objectives of this ergonomic evaluation included the following:

1. To determine the magnitude and severity of WMSDs among workers performing specified manual assembly jobs.

2. To identify sources of job stressors that may include biomechanical and behavioral work factors that could cause or contribute to symptoms of musculoskeletal discomfort and pain.

3. To provide recommendations in the form of engineering controls or administrative procedures that will reduce ergonomic stressors, thus allowing workers the opportunity to work without an increased risk of musculoskeletal injury or illness.

III. BACKGROUND

Square D Company manufactures both high-voltage and current instrument transformers used for revenue metering of power usage. The instrument transformers, which are designed to handle large electrical loads (69 to 345 kV), are assembled in the high-voltage winding and taping department (the area under evaluation) of the high-voltage group. Completely assembled units are two to six feet long and may weigh more than one hundred pounds. Because each unit is custom-designed and custom-built to purchaser specifications, the assembly process is not well suited for production by assembly line or automation. More than 80% of the time, assemblers manually apply insulating paper and aluminum strips in uniform layers around the units. The work requires a variety of skills involving high levels of dexterity and precision, which may take up to three years to develop. Task sequences are largely unstructured, allowing assemblers some autonomy in how they perform their work. Assemblers can thereby alter task sequences and work pace to accommodate individual needs as long as job specifications and production goals are met. A single assembly task may take as little as a few minutes (e.g., using a mallet) or as long as 48 hours (e.g., wrapping and taping larger units), depending on the product's specifications and the task involved. An assembler may perform several tasks on a single unit, working for hours or even days before transferring it to another station.

Approximately 30 employees work in the high-voltage winding and taping department. All work is performed during 8-hour day shifts over a 5-day work week. Employees sometimes work overtime, but company management stated that their policy does not allow employees to work more than 10 hours per day, and that the number of workers is increased by contract or permanent hires if overtime exceeds 10% of regular work time.
NIOSH investigators selected manually intensive jobs for evaluation. The main tasks of these jobs are described below.

A. Winding Jobs

The bulk of the transformer core is created during the winding process. The assembler operates a machine that winds wire, corrugated paper, and crinkled (crepe) paper around a firm cardboard spool. The assembler uses a toggle switch and foot pedal to activate the rolling spindle and control the spin rate. Periodically, the assembler stops winding to manually trim or reposition the paper. The amount of wire and paper wound onto the spool depends on design specifications and standards. Winding jobs take 4 to 8 hours for smaller units and over 30 hours for larger units.

Following the winding process, the filled spool is slipped in and attached to the core at the end of an electrode pole. The unit is then transferred to a wrapping and taping station.

B. Wrapping and Taping Jobs

These jobs have three stages: an initial cutting and taping stage, a stem-taping stage, and a final wrapping stage. Assemblers usually work on one transformer at a time, and perform all three stages of the process. Wrapping and taping jobs take 8 to 12 hours for smaller units and over 40 hours for larger units.

1. Initial Cutting and Taping

The unit is placed in a jig with its core fitting over a rod and its stem resting on a stand. This device allows rotation perpendicular to the long axis of the stem. The assembler creates a doughnut-shaped core by pulling, stretching, and taping the corrugated and crepe paper from the spool over and through the metal core at the end of the electrode pole. The assembler further shapes the unit by using conventional scissors to trim materials and cut wedges in the paper, and using strips of adhesive tape to fasten paper edges. Occasionally, the assembler uses a large wooden mallet to shape the core and to pound out any irregularities (such as air pockets) in the surface wrapping. All tasks in this stage are done by hand.

2. Stem Taping

After the "doughnut" is formed, the unit is transferred to a stem-taping machine. The stem of the electrode pole is placed horizontally through the center of the machine, with the core resting on a stand. The machine systematically wraps tape around the stem while travelling back and forth along the length of the stem. The assembler can operate the machine by automatically controlling its rate and direction, or operate it manually. Once the taping is complete, the transformer unit is transferred to a rotating jig, where the assembler manually applies aluminum strips to the core and adjacent part of the stem. The unit is then transported to the finishing area for final wrapping.

3. Final Wrapping

During this stage, the assembler applies aluminum, paper, and tape to the doughnut-shaped core while the unit rests on a stand similar to that of the stem-taping machine. The assembler rotates and positions the unit by hand in order to reach all surfaces. All tasks in this stage are done by hand. When final wrapping is completed, the unit is transferred to the high-voltage assembly department for oil immersion, casting, and testing.

C. Paper-Pulling Kit-Preparation Jobs

Although kit-preparation jobs were not initially identified as high-risk work, NIOSH investigators observed that the pulling and cutting of paper in these jobs could contribute to WMSDs. Employees on restricted duty worked in this area. Employees use outstretched arms to pull several lengths of paper, up to 5 feet at a time, from vertically placed rolls before cutting the paper to shorter lengths. At other times, they cut paper into smaller sheets directly from the roll with an industrial knife. They also operate a machine that partially strips rolls of paper, but must manually rotate the paper roll and set the blade on the paper.

IV. METHODS

A. Rationale for Ergonomic Investigation

Work-related musculoskeletal disorders can be caused or exacerbated by adverse work conditions and high physical work load, and can result in impaired work capacity [Hagberg et al., 1992, Armstrong et al., 1993]. Work conditions are influenced by the types of tools, work stations, materials, environment, and work methods used. Work load is influenced by how a task is performed (i.e., required level of effort), the rate at which the job is performed, and the duration of work [Putz-Anderson, 1988; Waersted et al., 1991]. Aspects of the social and cultural work environment and personal attributes of the worker also may operate as risk factors for the development and course of WMSDs [Armstrong et al., 1983].

Risk factors for WMSDs are those common attributes or characteristics in the work environment that are associated with increased probability of discomfort, impaired work performance, or disorders of the muscles, tendons, joints, and nerves. Risk factors vary for different tasks and for different workers. However, attributes of the worker's tools, materials, work station, and work methods combine to create common work-related risk factors.

B. Ergonomic Exposure Assessment

The ergonomic assessment consisted of three parts: (1) on-site data-collection in which measurements and videotape recordings were made of the work layout, workstation configuration, and types of tools used; (2) laboratory analyses of videotapes of specific work activities to identify and characterize risk factors for WMSDs; and (3) development of engineering and administrative recommendations to prevent and control WMSDs.

1. On-site Data Collection

NIOSH investigators first conducted a walk-through survey of the entire facility, then returned to the high-voltage winding and taping department, where employees were reported to have developed WMSDs. In general, jobs or work tasks that result in excessive postural loading, either from continuous or repeated static exertions, have been associated with the development of local muscle strain and fatigue. Furthermore, over prolonged periods, such stresses result in injury and WMSDs. Therefore, NIOSH investigators observed work processes and initially assessed work activities for a combination of risk factors (such as static loading, repetitive and forceful exertions, and awkward postures). NIOSH investigators made videotapes of the work activities for laboratory analysis. The videotapes offer a detailed recording of the postural and repetitive nature of the assembly jobs. Six assemblers, two from each of three manually intensive jobs in the department (winding, initial cutting and taping, and final wrapping), were randomly selected for videotaping.[1]

2. Laboratory Analyses of Videotapes

Analysis methods

1Employees consented to be videotaped.

A combination of two standardized postural-load measurement systems were used for the analyses. The Ovako Working-Posture Analyzing System (OWAS) was used to classify high-risk postural loads affecting the back, neck-and-shoulder area, and legs. OWAS is particularly sensitive to postural loading of the upper and lower trunk [Karhu et al., 1977]. It is based on a simple and systematic classification of work postures for each key work step. The Armstrong postural classification method [Armstrong et al., 1984] was used to provide a more detailed assessment of the shoulders, elbows, wrists, and hands. This method is used to classify arm and hand activities into 11 categories defined by deviations from neutral positions.

Sampling

Videotapes of two representative assemblers, one winding and one wrapping and taping, were selected for the analyses. Videotapes were sampled at a rate of one frame every five seconds to analyze trunk and neck postures using the OWAS system. Since the recordings were taped at a rate of 30 frames per second, the computer was programmed to systematically capture and digitize every 150^{th} frame. One-hundred-fifty frames were sampled to yield a total of 12.5 minutes of representative work activity per assembler. Because hands and wrists normally move faster than the trunk, videotapes were sampled at a rate of two frames per second to analyze the hands and wrists using the Armstrong method. One-hundred-fifty frames were sampled to yield a total of 1.25 minutes of work activity per assembler.

3. Evaluation and Redesign Criteria

The OWAS and Armstrong postural classification method were developed primarily to measure and categorize work postures that pose risks for musculoskeletal disorders. Once the stressful postures are measured and categorized, opportunities for changing the stressful task become more evident, thus identifying possible preventive strategies. The following three approaches are commonly used to reduce the risks of musculoskeletal disorders:

Reduce extreme joint movement

Excessive stress on joints and tendons is a principal cause of WMSDs. Therefore, frequently performed motions should be kept well within an acceptable range of motion for the joint in use. Work activities should ideally be performed with the joints at about the midpoint of their range of movement. Deviations about the trunk should not be greater than 15 degrees. Shoulder and arm deviations should not be greater than 20 degrees, and forearm and wrist deviations should not exceed 25 degrees from neutral.

Reduce muscle effort

Tasks that require prolonged and excessive muscle contractions to maintain a posture, assemble a part, or hold an ill-fitting tool contribute to the development of WMSDs. Therefore, jobs should be designed so that an assembler is not required to exert more than 15% of his or her maximum force for any particular muscle in a prolonged or repetitive way. All muscle contractions (including occasional ones) in excess of 50% of maximum voluntary contraction should be avoided. Moreover, if the effort or exertion required to perform a task can be reduced by as little as 10%, the experience of local muscle fatigue can be reduced by a factor of five or six times greater than 10%. By minimizing levels of local muscle fatigue, work quality is more likely to be sustained and the risk of injury reduced [Putz-Anderson, 1988].

Reduce repetitive movements

Highly repetitive and stereotyped manual movements contribute to WMSDs. Therefore, potentially aggravating production and design factors must be identified and altered to reduce the repetitive levels of a work cycle. Countermeasures include limiting the duration of continuous work or restructuring work methods. Repetitive movements become risk factors for WMSDs when the structures responsible for the motion suffer damage. Factors that affect joint damage include the force, acceleration, and direction of joint displacement; the temporal pattern of movements interspersed with pauses; and the actual size of the joint (i.e., larger joints are more vulnerable to repetitive motion). One rule of thumb that applies to the hands and wrists is the "30 second/50% cycle" rule [Anderson, 1988]. In essence, any motion of the hands that is repeated more than once every 30 seconds has been labelled as "repetitive." In addition, any task that has a single main activity that accounts for more than 50% of the task duration has been labelled as "repetitious." An example would be filling a box with 24 cans of food. The total task of filling the box may exceed 30 seconds, but the main activity of grasping each can and putting it into the box is repetitive because it is repeated more than once every 30 seconds. It is also repetitious because it accounts for more than 50% of the total task.

C. Medical Evaluation

The NIOSH medical officer conducted confidential interviews with 19 (70%) of the 27 employees at work in the high-voltage winding and taping department at the time of the site visit. All ten of the employees who were reported by management to have WMSDs were interviewed. Nine (51%) of the remaining seventeen employees were randomly selected for interviews. Employees were asked about their jobs and job tasks, symptoms of WMSDs, factors that aggravate symptoms, activities that are limited by symptoms, and medical attention for symptoms. The Occupational Safety and Health Administration (OSHA) Forms 200 (Logs and Summaries of

Occupational Injuries and Illnesses) for the years 1988 through 1992 were reviewed for WMSDs.

V. RESULTS

A. Ergonomic Exposure Assessment

1. Winding Jobs

Four main activities or work elements of this job were identified by the whole body assessment — winding, guiding, cutting, and taping. Winding was the most frequent work activity, accounting for 40% of the assembler's work time. During this work activity, an assembler manually held, pulled, stretched, and guided paper and wire onto a spool. Cutting with scissors accounted for 35% of the work time, and applying paper and tape accounted for 20%. Miscellaneous activities, such as adjusting the fixture, getting supplies, and applying glue were distributed over the remaining 5% of the work time.

All winding activities are performed in a standing position (Figure 1). The OWAS analysis showed that the assembler's neck and trunk were bent forward by more than 20 degrees for approximately 33% of the winding and taping activities, which accounted for nearly 60% of the total work time. The design of both older and newer winding machines requires assemblers to keep their neck flexed to view the operation. Because the machines are not vertically adjustable, the degree of flexion depends on the assembler's height. Some shorter (for example, 5' 2" in height) assemblers stand on a platform to achieve a workable height. Forward-bending trunk postures of 20 to 30 degrees accounted for about 50% of the total work time. Some forward bending at the trunk occurred during the guiding activity, which accounted for 20% of the time spent winding and taping. During the cutting activity, however, the back was typically straight. When operating the winding machine, most of the assembler's body weight was supported by the left leg and the right foot was on the control pedal with the right leg bent at the knee. Increased loading of the lower back and legs occurred as the assembler shifted her body weight from side to side to activate the foot control.

Using the Armstrong method, a range of hand and arm postures were identified during work on the winding machine. Moderate shoulder abduction of the dominant arm occurred nearly 30% of the work time (reaching to the side of the machine to adjust and guide the paper between spin cycles). Forearm pronation occurred 37% of the work time (placing the open hand under the rotating spindle and stretching the fingers in a "finger press" to guide the wire and maintain the wire's take-up tension). These and all other hand and arm postures were found to be well within the normal range of motions as defined by the AMA *Guides to the Evaluation of Permanent Impairment* [AMA, 1990]. A wooden mallet was used less than 10% of the work time to remove wrinkles or air pockets between the layers of insulation. Force levels were consistently under 10 kg, or 15% of maximum capacities for the average worker. Holding durations, however, often exceeded the 30-second limit. Finally, postural deviations of the trunk, arms, and wrists exceeded 15 degrees and 20 degrees for durations of nearly 30% of the work activity. Repetitive frequencies were low with the exception of cutting motions that resulted in mechanical contact of the finger and thumb with the scissors.

2. Wrapping and Taping Jobs

Initial cutting and taping

Five main activities were identified by the OWAS analysis — wrapping, smoothing, taping, cutting, and pounding. Nearly 60% of the work activity involved wrapping, 30% involved taping, and the remaining 10% covered miscellaneous activities (such as smoothing, cutting, and pounding). The trunk was bent forward approximately 25 degrees throughout the taping stages. The arms and shoulders were alternately elevated and lowered during nearly 40% of the work time. The work was self-paced, and assemblers interspersed their work with less stressful activities that allowed them to use their hands without raising their arms.

Data from Armstrong's method for evaluating the upper extremities indicate moderate-to-high shoulder, arm, and wrist deviations. The assembler's dominant arm was elevated at the elbow to nearly shoulder height for 60% of the taping sequences. The assembler passed the tape roll from one hand to the other while threading tape in and around the center of the doughnut-shaped core. During a taping sequence that lasted approximately 2 minutes, the assembler's wrists moved from moderate ulnar deviation to radial deviation every 0.8 seconds. Although the cutting activity takes up less than 10% of the time, it represents one of the more stressful activities because of the grip force required as well as the elevated arm positions (Figure 2).

Although the jigs that hold the units at this work station rotate, they were not designed to be easily raised or lowered. As a result, assemblers assumed various awkward trunk and arm postures to work on all sides of the unit. Specifically, an assembler of any height has to bend and reach through and around the transformer core during taping. Because a shorter-than-average assembler has to reach up and around the core, the shorter assembler may use up to 30% more muscle effort than someone of average height to attain the same forces necessary to pull and stretch paper around the core. On the other hand, a taller-than-average assembler has to maintain a stooped posture and use greater muscle effort to pull down on the paper.

Stem taping

The unit's stem is taped by a machine. Therefore, repetitive and forceful hand and arm motions were minimized at this station. However, assemblers, particularly those taller than 68 inches[2] (5'8"), must bend forward at the trunk when mounting the transformer onto the taping machine during the set-up stage.

Final wrapping

Activities of final wrapping are similar to the those of initial cutting and taping. The assembler had to reach in and around the unit's doughnut-shaped core. The larger the core diameter (which can be up to 0.3 meter), the more extended the arm reach. Typically, the assembler bent forward at the neck, shoulders, and trunk to apply tape around and through the center of the core. Required force levels can exceed 60% of muscle strength capability for assemblers who are shorter than 66 inches (5'6").[3] Ultimately, the size and weight of the unit determined how and how much it was maneuvered. For example, large transformers, which cannot be safely manipulated without the help of another person or a mechanical device, are moved less frequently.

3. Paper-Pulling Kit-Preparation Jobs

Employees performing this activity frequently maintained static postures and used high grip-force exertions. When manually cutting smaller rolls of paper with an industrial knife, the employee simultaneously held the roll steady while forcefully cutting through as much paper as possible. Cutting larger rolls of paper, which was done by machine, required less use of the hands, but required much arm and shoulder activity. The lack of adjustability of the chair at the machine probably contributed to the increased arm and shoulder activity. Employees in this work area also handled rolls of paper weighing from 20 to 190 pounds up to 20 to 25 times a day. While handling the various rolls of paper, the employee often had to negotiate a bar between the upper and lower shelves of the tables where the rolls of paper were placed.

B. Medical Evaluation

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[2] A person of this height, regardless of gender, would be taller than 60% of people in a population sampling of equal numbers of American men and women [Gordon et al., 1989].

[3] A person of this height, regardless of gender, would be shorter than half the people in a population sampling of equal numbers of American men and women [Gordon et al., 1989].

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1. Confidential Medical Interviews

Table 1 shows the age and work-history characteristics of the 19 interviewed employees. All but one of these employees worked at Square D for 14 or more years. Seventeen (89%) of the interviewed employees, including seven (78%) of the nine randomly selected employees, reported musculoskeletal symptoms. Table 2 shows the locations of symptoms reported by the symptomatic employees. Twelve (71%) of the seventeen symptomatic employees reported hand-wrist symptoms (Table 3). Eleven (92%) of the employees with hand-wrist symptoms related their symptoms to pulling paper or wrapping and taping. Two of these workers were assigned to the kit-preparation area for restricted duty because of hand-wrist problems. Five of the employees with hand-wrist symptoms reported developing problems within one year after starting to wrap and tape. Less frequently reported causes for hand-wrist symptoms included pulling cotton, pounding (e.g., cases in kit-preparation area) or hammering (e.g., plug in current transformer), use of scissors, hand winding on larger units, and overtime work. Five (42%) of the twelve employees with hand-wrist symptoms sought medical attention for their problems. Two were treated with surgery and two with cortisone injections. The surgically treated employees reported that they had scheduled surgery for the beginning of long weekends so they would be able to report to work at the beginning of the following week.

Fourteen (82%) of the seventeen symptomatic employees reported musculoskeletal symptoms in parts of the body other than the hand or wrist. Employees attributed shoulder symptoms to leaning over large units during winding, hammering, pulling paper or cotton, cutting, and use of an older machine; low back symptoms to wrapping and taping larger units, leaning over the winding machine, and prolonged standing; hip-buttock symptoms to leaning forward constantly and using the foot pedal; and lower extremity symptoms to using the foot pedal. Five (36%) of the fourteen employees with non-hand-wrist symptoms had sought medical attention. Three had been treated with cortisone injections. Of the 17 employees who reported any symptom, a few stated that they did notseek medical attention because they did not think it would help.[4]

Some of the interviewed employees reported that work-pace standards were set by faster assemblers or during continuous work without rest breaks. A few employees reported that philosophies about work pace differed among supervisors. Employees reported that they appreciated supervisors who understood that an increased work

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4Employees with severe symptoms were advised by the NIOSH medical officer to seek medical attention if they had not already done so.

pace could result in an increased number of injuries and a decrease in product quality.

Some employees expressed concerns about sinus problems and sneezing, which they related to airborne paper dust or exposure to solder fumes. An employee related difficulty reading calipers to poor lighting.

2. Review of Company Records

*Table 4 summarizes the WMSDs in the high-voltage winding and taping department that were reported on the OSHA Forms 200 for 1988 through 1992. Approximately half of the employees in the department had reportable WMSDs over this 5-year period. Employees with surgical treatment for WMSDs were not on record as having lost work days and company management reported that Square D had no lost work days for the previous seven years. However, about one-third of the employees in the department had been on restricted work activities for more than one day. The number of days on restricted work activities for the department was equivalent to 9 person-months for the 5-year period.

VI. DISCUSSION

The rate (14 employees in a department of 28-30 employees over 5 years) of WMSDs reported on the OSHA Forms 200 indicate that WMSDs are a problem among employees who work in the high-voltage winding and taping department. Although less than half (47%) of the interviewed employees were not previously reported to have WMSDs, the high prevalence (78%) of WMSD symptoms among these employees indicates that this problem is more widespread than the company originally suspected. The prevalence had probably been underestimated because employees were not reporting their symptoms to the company. Some factors that could result in nonreporting include inadequate employee education and training about hazards, risks, and preventive measures; and employees' lack of confidence that supervisors or managers would take their concerns and suggestions seriously. In addition, the management policy and employee practices that resulted in no recordable lost work days for seven years, despite the presence of surgically treated employees, masked the severity of WMSDs in the department.

Some of the symptoms reported by the interviewed employees indicated severe WMSD. For example, eight symptomatic employees reported decreased hand grip or hand numbness, which are consistent with WMSD, such as carpal tunnel syndrome. Although the decreased grip could be related to pain alone, hand numbness at night or on waking indicates possible involvement of a nerve, such as the median nerve in carpal tunnel syndrome.

The reported symptoms (Table 2) are consistent with the potential risks identified by the ergonomic exposure assessment as well as the activities that employees identified as causes of their symptoms.

Symptomatic employees attributed shoulder, low back, hip-buttock, and lower extremity symptoms to winding jobs. This is consistent with the OWAS analysis that showed winding jobs to have the potential for inducing significant neck, back, and leg stress. Potential for stress to the neck and back is related to an assembler's height and the lack of vertical adjustability on the winding machine. The standing position and use of the foot pedal contribute to the potential for stress to the back and legs. Upper extremity symptoms were rarely attributed to winding jobs. This is consistent with the finding that all arm and hand postures for winding jobs were well within the normal range of motions as defined by the AMA *Guides to the Evaluation of Permanent Impairment* [AMA, 1990].

The OWAS analysis showed that wrapping and taping jobs may pose a moderate risk for WMSDs of the back, shoulders, and arms. The potential for risk to the back is related to bending forward at the trunk during taping. The potential for risk to the shoulders and arms is related to reaching in and around the core during taping. Because of the size and shape of the transformer core and the lack of easy vertical adjustability of the jigs, awkward trunk and arm postures can affect an assembler of any height. As the amount of bending and reaching increases, the risk for musculoskeletal fatigue and strain also increases. The risk to the arms and shoulders may be somewhat reduced by self-pacing and interspersing work with less stressful activities, both of which allow opportunities for recovery from short-term muscle fatigue.

Evaluation by the Armstrong method showed that wrapping and taping jobs have a potential for WMSDs related to the moderate-to-high shoulder, arm, and wrist deviations. The repetitive and awkward wrist postures indicate moderate-to-high muscle-tendon loading. Internal muscle-tendon forces are increased when force is applied with the hands and arms in awkward positions. These findings are consistent with reports of hand and wrist WMSD symptoms that interviewed employees attributed to hand taping.

During set-up at the stem-taping station, the potential for risk of back injury is related to the various weights and shapes of the transformer units and the spinal stress of mounting and dismounting the units while bending forward at the trunk. These factors may increase the risk of acute as well as chronic trauma to the back. Tall assemblers may be at increased risk because they must bend more during this activity.

Because the activities of final wrapping are similar to those of initial wrapping and taping, the risks to assemblers during this stage are similar to the risks encountered during initial cutting and taping.

Although kit preparation was designated a light-duty assignment, the required activities have the potential for inducing stress to an employee's upper extremities. Risks for WMSDs in this work area are related to the use of high grip-force exertions, maintenance of static postures, handling of large rolls of paper, and lack of chair adjustability at the cutting machine. Some of the kit-preparation activities may still be too stressful for post-surgical employees and could prolong recovery time.

Because work in the department is basically self paced, most of the reported WMSDs are probably related to assemblers' postures and movements during physical interactions with the product or machines. However, some employees reported that production standards were set using faster assemblers and continuous work periods without rest breaks. Faster-paced standards lead to increased repetition which could contribute to the prevalence and severity of WMSDs in the department. Supervisors' philosophies about work rates could also affect the development or prevention of WMSDs.

Although air contaminants and lighting were not evaluated during this investigation, some employees reported respiratory irritation from paper dust in the air and trouble seeing their work because of inadequate lighting. In addition to affecting performance of tasks that require precision, poor lighting could cause WMSDs if employees maintain awkward postures to better see their work.

VII. RECOMMENDATIONS

Because WMSDs are related to multiple factors, successful prevention and control of WMSDs require a multifactorial approach. The following recommendations include engineering controls, administrative controls, education and training, and a medical program. These measures should be integrated into an ergonomics program, with input from employees as well as consultants and management.

A. Engineering Controls

Use of engineering controls is the preferred method of preventing WMSDs. The focus of engineering controls should be to make the job fit the employee, rather than making the employee fit the job. The engineering recommendations discussed below focus on the workstation, work methods, or tools to the reduce biomechanical hazards identified during this investigation. These recommendations should be considered an initial attempt in providing engineering solutions to prevent musculoskeletal problems in the workplace. Employees, production managers, and sales representatives of machines and equipment may be able to recommend other improvements and alternatives. Feasibility would be better addressed by the technical personnel and production managers. Effectiveness in preventing WMSDs would be better addressed by the employees who use the machines and equipment.

1. Winding Jobs

a. Modify the winding machine to make the point of operation vertically adjustable. This modification would allow an assembler to move the work into a position that would reduce the need for prolonged neck flexion.

b. Provide adjustable stands to offer some relief from the static postural stance that an assembler maintains while the machine is winding. Figure 3 illustrates two examples of sit-stand support stools.

c. Investigate alternatives to the foot control on the winding machine to reduce the loading of the lower back and legs that occurs when an assembler shifts his or her weight from side to side while using the foot pedal.

2. Wrapping and Taping Jobs:

Initial cutting and taping

a. Provide a more adjustable jig which should be adjustable vertically as well as for rotation (such as the one illustrated in Figure 4). For example, a hydraulic stand designed to raise and lower the entire unit should minimize the amount of bending and reaching currently required. This design would also allow an assembler to assume a posture with greater mechanical advantage when cutting, pulling, and stretching the paper.

b. Provide a mechanical device for pulling and stretching the paper to alleviate the stress to an assembler's upper extremity.

Stem taping

a. Situate the stem-taping machines close to the initial cutting and taping jigs.

b. Provide readily available mechanical assistance to move the transformer from station to station.

Final wrapping

Provide an adjustable stand similar to the jig recommended for initial cutting and taping. This stand should be vertically adjustable and be able to easily rotate the transformer unit perpendicular to its long axis. A more maneuverable stand should reduce some of the extreme postures, such as bending and reaching while handling various transformer shapes and sizes.

3. Paper-Pulling Kit-Preparation Jobs

a. Provide mechanical devices, such as a wheeled cart containing a cylindrical pole protruding horizontally from the front. To load and unload paper rolls, the pole could be controlled by a hydraulic system to allow for vertical adjustments. Use of such devices would allow anyone to transport paper rolls without assistance.

b. Modify the storage area and orientation of stored paper rolls to make rolls more easily accessible. For example, storing the rolls on shelves with distinctly separate rows would provide easier access to the paper. Stacking rolls horizontally by paper size would also reduce the need for extensive searching for specific roll sizes.

c. Modify the work area to reduce bending. For example, instead of keeping paper rolls on the lower shelves of the table, rolls could be placed on vertical rods mounted on a rotating platform (similar to a lazy susan) on top of the table. Each platform could hold a number of rods. Each rod should be able to be locked into at least two positions — horizontal to allow easy placement of the paper roll and vertical to allow easy access for paper pulling. The turntable could be rotated for access to the other rolls of paper. This design would reduce bending related to grabbing rolls from a table's lower shelf.

d. Install a fixture to hold smaller rolls for manual cutting.

e. Modify the cutting machine to allow mechanical, rather than manual, turning of the paper roll. Provide preset slots on the rotational part of the cutting machine for mechanical adjustability when setting strip widths. This change would make the human-machine interaction more efficient and could effectively reduce upper extremity musculoskeletal strain as well as eyestrain.

f. Provide an easily adjustable chair at the cutting-machine station.

B. Administrative Controls

Administrative controls should only be used as temporary measures until engineering controls are implemented or as longer term measures only when engineering controls are not technically feasible. Job rotation and rest pauses are reasonable administrative measures to prevent WMSDs.

1. Consider rotating jobs to alleviate physical fatigue and stress of a particular set of muscle, tendon, and nerve groups. Caution should be used in deciding which jobs to rotate. Although different jobs may appear to have different stressors, they may actually require the same physical demands.

2. Provide rest pauses to relieve fatigued muscle and tendon groups. Optimum durations of pauses depend on a task's overall effort and total cycle time (Putz-Anderson, 1988).

C. Medical Program

1. Educate production workers and supervisors on the early symptoms and signs of WMSDs. Encourage employees to report symptoms as soon as they become aware of them.

2. Provide evaluation of WMSD symptoms by a health care professional when symptoms are first reported.

3. Appoint a medical professional who is familiar with ergonomic principles to administer the medical program. The medical professional should also be familiar with the jobs and activities within the workplace.

4. When a WMSD is diagnosed —

   a. Institute medical evaluation for return-to-work capabilities. The assessing clinician should be familiar with the physical demands of various alternative jobs and the principles for matching an injured employee's physical abilities with job demands.

   b. Allow sufficient time off work or time at work with restrictions to allow the affected muscle, tendon, and nerve groups to heal. The number of days off work or on work restrictions should depend on the affected employee's individual response to rest and treatment. Work restrictions should truly protect the affected body part.

   c. Provide slower paced, lower force tasks to employees returning to work after a WMSD injury to allow reconditioning of the injured muscle, tendon, and nerve groups.

5. After surgical treatment of a WMSD, allow sufficient time off work for healing of the operative site and all affected muscle, tendon, and nerve groups. Although NIOSH does not have a policy on time off after the surgical management of carpal tunnel syndrome, the following guidelines have been recommended by NIOSH investigators in the past [NIOSH, 1989]:

Amount of time off work	**Amount of repetition and force**		
	None*	**Low to moderate****	**High†**
Average	3 weeks	6 weeks	12 weeks
Minimum	10 days	21 days	42 days

*Jobs with cycle times of 5 minutes or more, no lifting of objects over 1 pound, no use of hand tools, no hand pinching or gripping [Putz-Anderson, 1988].

**Jobs with cycle times between 30 seconds and 5 minutes, lifting of objects less than 2 pounds during most cycles, occasional use of hand tools [Putz-Anderson, 1988].

†Jobs with cycle times of less than 30 seconds, lifting of objects more than 2 pounds during most cycles, use to hand tools for more than half the job cycle [Putz-Anderson, 1988].

6. Institute a surveillance program to monitor WMSD trends in the workplace. This would also provide information about the effectiveness of measures taken to prevent WMSDs.

7. Properly record WMSDs on the OSHA Forms 200.

8. Implement engineering and, if necessary, administrative measures to control and prevent WMSDs in tasks that are identified by the surveillance program as causing previous WMSDs.

D. Integrated Ergonomics Program

Develop and implement an ergonomics program that integrates the following:

1. Commitment and support of the program from management and employees.

2. Committee to oversee the ergonomics program. The committee should include representatives from employees, supervisors, and medical consultants as well as management.

3. Committee members trained on the ergonomic and medical principles of WMSDs.

4. Education and training on risk factors and preventive measures. Early recognition of WMSDs should be emphasized. To minimize

misinterpretation of the contents of training, supervisors, managers, and production workers should receive the same training.

5. Systematic evaluation of all jobs with regard to existing and new work practices, jobs, tools, and equipment to identify stressors such as repetition, force, vibration, and postures.

6. Evaluation of program's effectiveness, including assessments of employee acceptance of work changes, job transfers and lost work time related to WMSDs, and trends in the incidence rates of WMSDs.

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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.

IX. AUTHORSHIP AND ACKNOWLEDGMENTS

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U.S. Department of Labor, OSHA, Region IV
Employee representative to the Health and Safety Committee

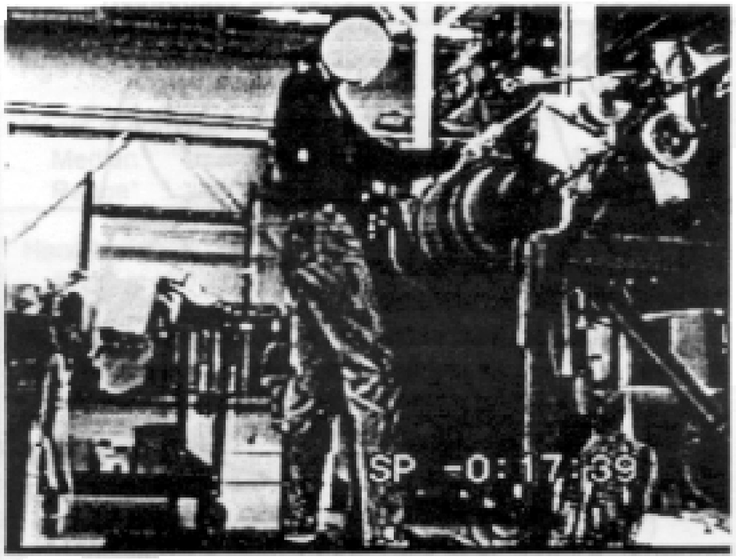

Figure 1. **Winding Job**

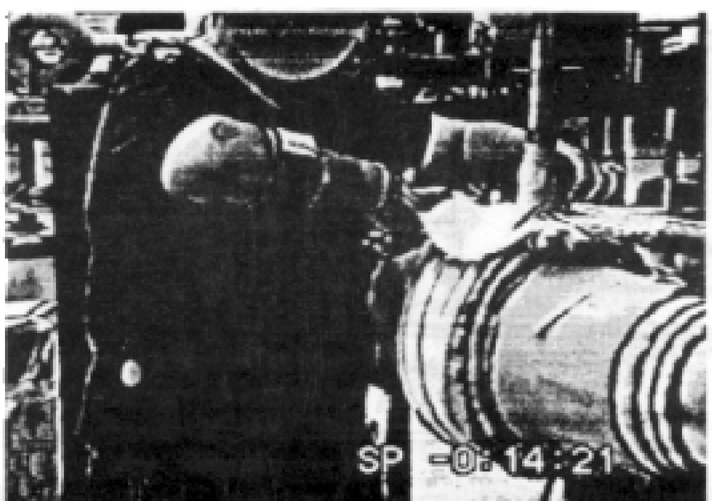

Figure 2. Cutting and Taping Job

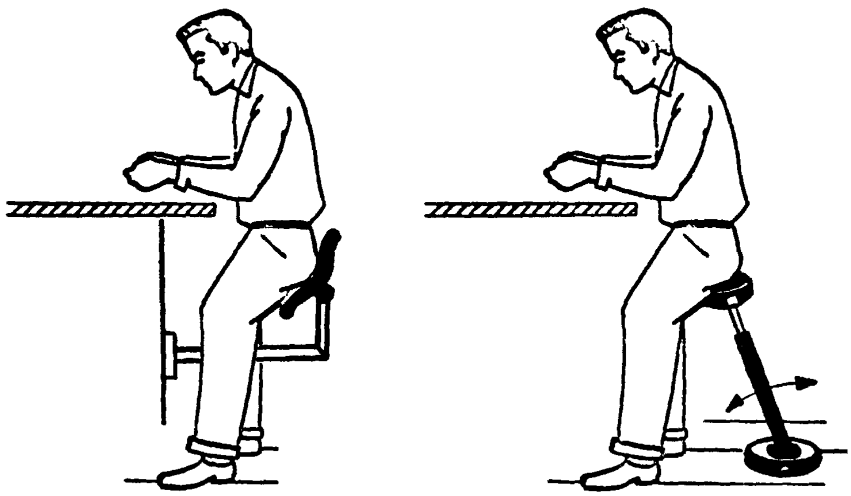

Figure 3. Examples of Sit-Stand Support Stools

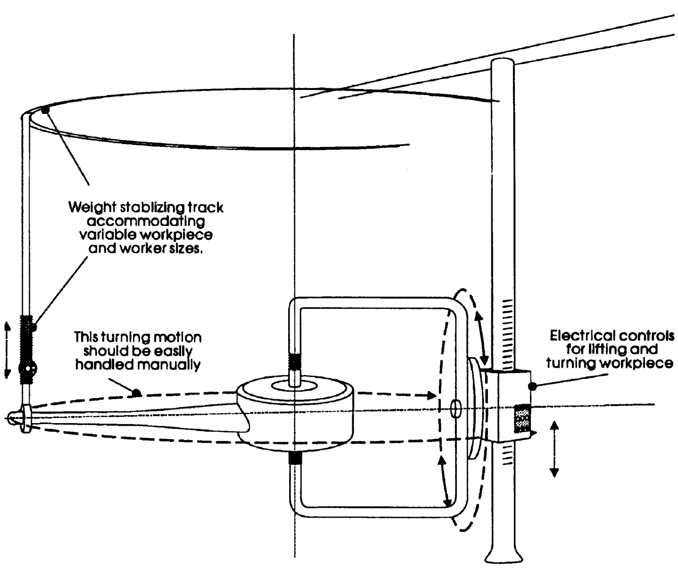

Figure 4. Example of an Adjustable Work Stand

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Square D Company
Clearwater, Florida
March 29-30, 1993

Table 1
Responses of the 19 interviewed employees

Age	38 - 59 years
Years at company	
Median	15 years
Range*	2 - 23 years
Hand taping	
Number (%) employees	12 (63)
Percent of time**	50 - 100%
Hand winding	
Number (%) employees	4 (21)
Percent of time**	25 - 100%
Machine taping	
Number (%) employees	7 (37)
Percent of time**	25 - 100%
Machine winding	
Number (%) employees	2 (11)
Percent of time**	20 - 100%

*All but one employee worked for 14 or more years.

**Estimated amount of time employees reported they spent performing this type of work.

Table 4
Summary of work-related musculoskeletal disorders*
among high-voltage winding and taping employees
reported on the OSHA Form 200 from 1988 through 1992**

Part of body	5-yr total	1992	1991	1990	1989	1988
Finger	1	1				
Hand	3		1		1	1
Wrist	2	1	1			
Elbow	3		1		1	1
Shoulder	3		2		1	
Arm NOS†	3		2	1		
Low back	2			1	1	
Back NOS†	1					1
Hip	1				1	
Ankle	1				1	
Total number of workers affected	14††	2	4††	2	6	3
Number of worker with restrictions	10††	1	4††	2	3	2
Days of restricted work activity	198	11	137	25	13	12
Days away from work	0	0	0	0	0	0

*Acute musculoskeletal injuries (such as strains and sprains) as well as disorders associated with repeated trauma, because of the possibility of common risk factors.

**The plant was remodeled in 1988-1989.

†Not otherwise specified.

††Two employees were affected in more than one year and two employees were affected in more than one part of the body.

Table 2
Location of symptoms
reported by 17 symptomatic employees

Part of body	Number reporting (%)
Hand-wrist	12 (71)
Hand	10 (59)
Wrist	9 (53)
Feet	7 (41)
Shoulder	6 (35)
Low back	6 (35)
Hip-buttock	5 (29)
Thigh	4 (24)

Table 3
Hand-wrist symptoms reported by 12 of the 19 interviewed workers

	Number (%)
Any symptom	12
Pain*	11 (97)
Decreased hand function** or hand numbness	8 (67)
Decreased hand function	6 (50)
Hand numbness at night or on waking	5 (42)
Ganglion cyst	3 (25)

*Six employees reported wrist pain. Three employees reported pain on the back (dorsal aspect) of the hand over the bones between the wrist and the thumb and index finger (first and second metacarpals).

**Trouble opening jars or doors, trouble handling fork or small objects, dropping of hand-held objects, indicating decreased grip (which could be related to pain alone or to neuromuscular impairment).

APPENDIX
Glossary

Abduction Movement away from the central axis of the body away from the median plane.

Activity (See **Job/Task/Activity**.)

Adduction Movement toward the central axis of the body.

Armstrong postural classification method Method used to classify shoulder, elbow, wrist, and hand activities by deviations from neutral positions.

Carpal tunnel syndrome Condition caused by the compression of the median nerve in the carpal tunnel, a passage in the wrist through which the tendons that flex the fingers pass from the forearm to the hand. It is often associated with tingling, pain, or numbness in the thumb and first three fingers.

Cumulative trauma disorder Term used to identify the group of musculoskeletal disorders involving injuries to the tendons, tendon sheaths, and the related bones, muscles, and nerves of the hands, wrist, elbows, and arms.

Exertion Applied manual effort.

Flexion Movement that decreases the angle between two adjacent bones.

Extension Movement that increases the angle between two adjacent bones.

Ganglion cyst Tendon sheath disorder in which the affected sheath swells up with synovial fluid and causes a bump under the skin, often on the wrist.

Job/Task/Activity Each job is composed of one or more tasks, each task is composed of one or more activities, and each activity is composed of one or more motions.

OWAS Ovako Working-Posture Analyzing System, particularly sensitive to postural loading of the upper and lower trunk; used to classify high-risk postural loads affecting the back, neck-and-shoulder area, and legs.

Pronation Medial rotation of the forearm that brings the palm of the hand downward (turning the wrist so as to have the palm down).

Supination Lateral rotation of the forearm that brings the palm of the hand upward (turning the wrist so as to have the palm up).

Task (See **Job/Task/Activity**.)

Therbligs Elements of work consisting of fundamental movements or acts (reaching, grasping, moving, etc.).

WMSD Work-related musculoskeletal disorder.